The Arctic Research Program, Fiscal 2007

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Program Description

The Arctic Research Program is a component of the NOAA Climate Observations Division and focuses on climate-related observations of the broad Arctic region. The observations include both physical and ecosystem indicators of climate change in the Arctic and as such the program provides information to all the NOAA goal teams: ecosystem (changing ecosystems under conditions of reduced sea ice cover, Arctic climate change and global responses, Arctic climate change and its effect on North American weather and Arctic Climate Change, sea ice change and commerce in the Arctic region.

The program follows the advice of the Science Steering Committee and the implementation plan developed by the Interagency Study of Environmental Arctic Change SEARCH: plans for Implementation during the IPY and Beyond. Observations focus on atmospheric variables such as clouds, radiation and aerosols that influence Arctic climate; on sea ice thickness and motion; on ocean climate such as water column temperature and salinity structure and currents, primarily in the ocean gateways to the Arctic (including the Bering Strait, Chuckhi Sea region, and the passages from the Arctic to the Atlantic Ocean) and changing ocean chemistry and biology in these regions to detect the impacts of physical climate change on the Arctic ecosystems and the globe as a whole. Additionally, activities are undertaken to analyze and integrate observations of the program and historical data from diverse sources. The program conducts web-based outreach activities, is involve in museum Arctic Exhibit development (e.g The Museum of Natural History) and supports a State of the Arctic report. The program is active in international coordination of Arctic observation activities, working with the Arctic Council, the International Arctic Science Committee and on a bilateral basis with Canada, Norway, Russia, China and others.

Developing an Arctic Observing Network: an IPY Legacy for NOAA

Both paleo-data and recent environmental observations show that climate changes in the Arctic have and still play a major role on the Earth's climate. Changes in the Earth's albedo and fluxes in fresh water from increased river flow, reduction in sea ice cover and melting ice sheets are major contributors to rapid global change by altering surface temperatures, contributing to sea level rise and affecting global thermohaline circulation. The question arises, is the Arctic approaching the climate conditions that have in the past stimulated abrupt climate change elsewhere on the planet? How close is the present state of the Arctic to a tipping point, where formerly stable climate regimes alter to new states?

What will we face if the climate of the Arctic changes as dramatically as models predict? The Arctic contains many living and non-living resources of significant economic and social importance; the US has a strong economic base in Bering Sea fisheries, esthetic concerns over Arctic marine mammals, and concerns over native subsistence hunting rights. Can we imagine a world without polar bears? What will happen to weather and climate over North America when the ice disappears?, What will be the state of storms, will the fish migrate to new habitats, what will become extinct? How will changing Arctic conditions affect drought, rainfall, tornadoes, and hurricanes in the mainland U.S.? How will changing ice conditions affect global commerce? All of these topics lie squarely in NOAA's field of responsibilities. NOAA is the agency responsible for tracking long-term environmental change and for modeling the evolution of change and its impacts.

More than 60 nations of the world are celebrating the International Polar Year in 2007 and 2008 to address global environmental change, and teleconnections from the poles to the equator. An important goal of the International Polar Year is to develop global legacies that will continue to provide information about polar induced climate changes for decades to come. Our goal in the Arctic Research Program is to facilitate the development an Arctic Observing Network as a long-lasting Legacy. Both NOAA and NSF have agreed to lead the development of the AON and continue to engage international partners in this effort. This is an outgrowth of the recommendations provided by the interagency SEARCH (Study of Environmental Arctic Change) Implementation Plan drafted in 2005. AON should accommodate observations in the Arctic Ocean (including physical, chemical and ecosystem observations), in, under and above the sea ice cover, measurements of the flux of atmospheric properties over space in time at a suite of climate observatories that will ring the Arctic, and terrestrial fluxes of greenhouse gases and fresh water.

The SEARCH implementation plan presented a series of maps annotated by proposed observing station locations. The Arctic Research Program in the Climate Program Office identified these stations as the 100% international contribution to the Arctic Observing Network. The United States contribution to this network is not yet developed, yet NOAA's initial plan is to focus efforts on the Pacific-Arctic region, (that area from the Bering Strait, to the Lomonosov Ridge bordered by the Arctic margins of Canada, USA and Russia.

CPO's Role in the Arctic Observing Network Development

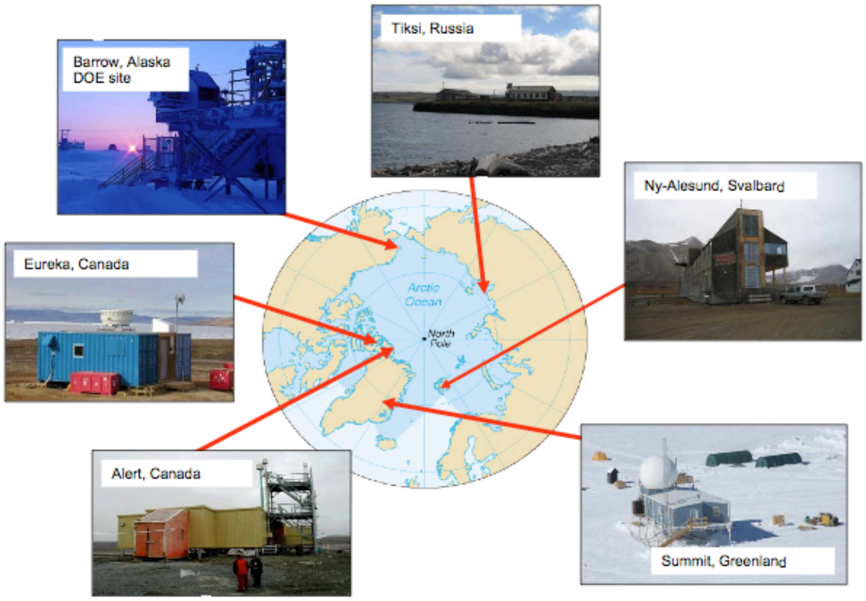
1. Arctic Climate-Atmospheric Observatory Network

Contact: Taneil Uttal, ESRL

The Arctic Research Program has undertaken an agency leadership role in the Implementation of the International Arctic System for Observing the Atmosphere (IASOA)**-** As part of the SEARCH implementation plan, the Arctic Research Program will support with international partners 3-5 Observatories around the rim of the Arctic Ocean. Barrow, Alaska (Already supported by NOAA ESRL and the DOE Atmospheric Radiation Monitoring program). The second observatory in the network is at Eureka, Canada on Ellesmere Island. The third link in the planned network will be located at Tiksi in Siberia, Russia and preparatory work began there in 2006 with the completion of the first building for the observatory. NOAA will coordinate with an already established atmospheric observation program in Ny-Alesund, Norway and the Greenland, Summit Station to complete the circumpolar network. The goal of the observatory network is to provide long time-series data on clouds and cloud properties, aerosols, radiation, and trace gases. The data will support research on atmospheric climate processes, provide calibration/validation data for current and planned satellite sensors, and provide data to develop and test global and regional climate models with an end goal of answering questions of attribution. It is anticipated that the Observatory sites will also be the focus of a number of interdisciplinary measurements of regional hydrology, permafrost, ecosystems and the cryosphere that will link the atmospheric measurements into the broader Arctic system. The program is heavily leveraged against Canadian and Russian programs, and has a vigorous interagency cooperation with NSF and DOE.

On March 7-9, 2007 there was a planning meeting in Boulder, Colorado to develop a work requirements document for the new facility. This meeting was open to all researchers with an interest in doing research in the Tiksi area regardless of current funding status. The four primary goals of the meeting were to:

1. Approve a final Work Requirements Document to serve as a basis for construction in the summer/fall of 2007;
2. Begin coordination of measurement activities and programs to fully utilize resources between programs, disciplines and countries;
3. Training of Tiksi personnel on the first wave of instruments intended for the Tiksi Observatory;
4. Establish a Tiksi Science Steering Committee.



NOAA hosted a delegation from Russia that included engineers from Tiksi, managers from the Moscow and Yakutsk Roshydromet offices, and Russian scientists with research interests in Tiksi. The Arctic research community was invited to attend this meeting with requests, experience, expressions of interest and ideas for development of this new research and monitoring facility.

In 2007, the following actions were undertaken to advance the development of these sites:

* Planning meeting organized with NSF and Roshydromet to develop observatory facilities in Tiksi, Russia.
* Visit to Tiksi, Russia to finalize site layout and building plans/location
* Installation of micrometeorological tower in Eureka, Canada

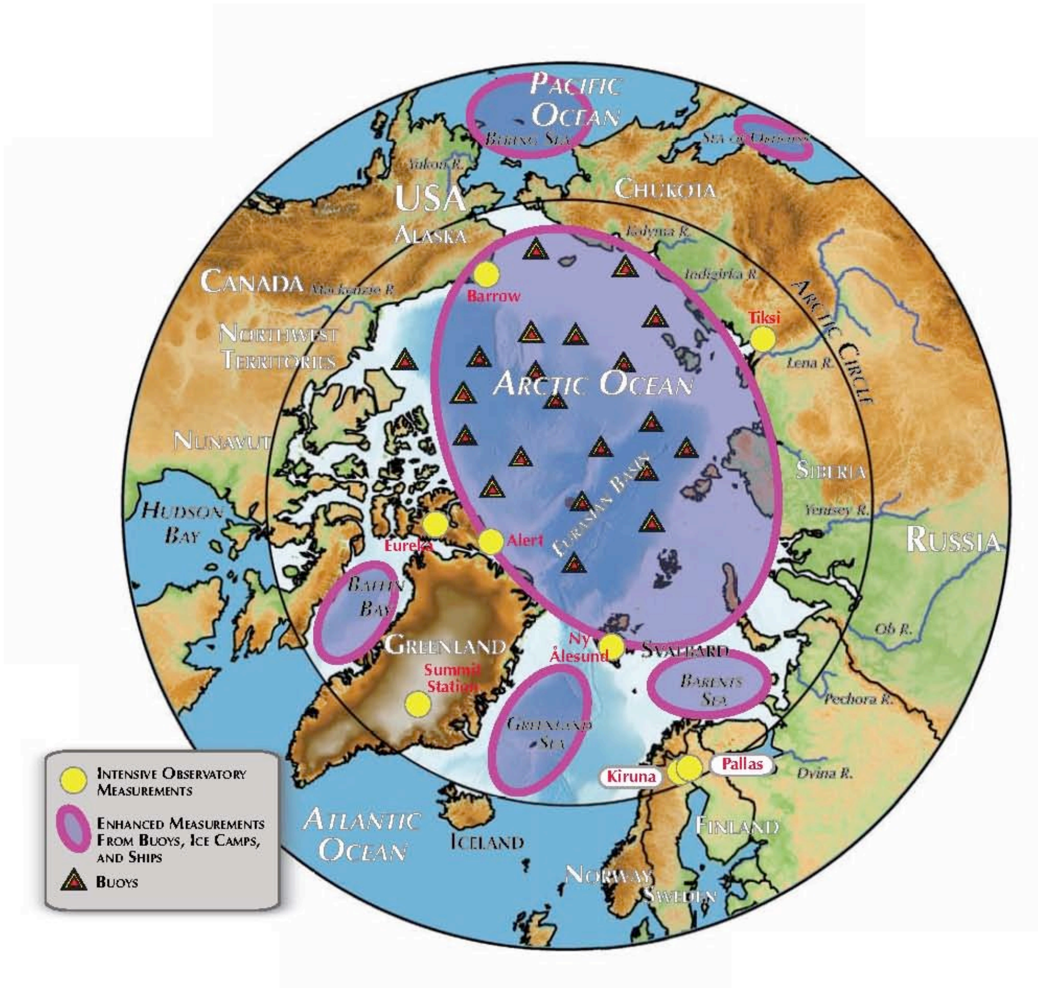


Figure 1. Priority areas for atmospheric observation activities. *A SEARCH atmospheric observing program should include coordinated intensive observatory measurements (yellow dots) in Barrow, Alaska; Alert and Eureka, Canada; Ny-Ålesund, Norway; Tiksi, Russia; the Greenland Summit Station; Pallas, Finland; and Kiruna, Sweden, as well as the inclusion of upper air measurements within existing ocean data collection activities (pink circles), including those from potential buoy deployment areas (see Figure 2). Weather station networks, unmanned aerial vehicles (UAV), and satellite data represent additional sources of atmospheric observations (not shown). Coordination of efforts between atmospheric observatory programs, integration with other interdisciplinary activities, and international support to reinstate, enhance, and establish new atmospheric observations throughout Siberia north of the Arctic Circle will significantly enhance the potential for understanding regional differences of atmospheric changes in the Arctic.*

2. Ocean and Sea Ice Observations
Contact Person: K. Crane kathy.crane@noaa.gov

The NOAA Arctic Program is also working with partners to implement the Ocean part of the **Arctic Observing Network (AON).** The NOAA portion of the AON will be a subcomponent of the NOAA Integrated Ocean Observing System and is represented in the SEARCH implementation plan figure 2. There are 3 NOAA-supported elements to the AON: 1) ***oceanographic moorings*** along the shelf and slope, in the deep basin of the Arctic Ocean (NABOS) and across the Pacific Gateway to the Arctic, the Bering Strait; 2) ***ship- based*** observations focused on ecosystem-physical interrelated indicators of climate change in the Northern Bering Sea and the Chukchi Sea. NOAA conducted its first Arctic Ocean research cruise with the Russian Academy of Sciences in summer 2004 through what has become known as the RUSsian-American Long-term Census of the Arctic (RUSALCA) project. One objective of RUSALCA is to document the changes in the physical state of the northern Bering Sea and Chukchi Sea, regions that have experienced significant change over the past few decades and that models predict will experience even greater change in the decades ahead. General ocean and atmospheric warming and loss of sea ice should be accompanied by changes in water column structure, and possible changes in circulation and flux through the Bering Strait, which may have implications for the entire Arctic and Atlantic Ocean beyond. A second objective of RUSALCA is to observe changes in ecosystem structure and productivity that result from the physical changes, and to identify a set of ecosystem indicators that might be applied throughout the Arctic marine region. Marine ecosystem alterations will affect Native subsistence harvests and possibly commercial fisheries and protected mammals and birds. Planning is underway for a major international research and observations expedition during the International Polar Year in 2008. The current strategy is to conduct a multidisciplinary cruise every 4 years with mooring and physical oceanographic based expeditions conducted annually. Additional RUSALCA goals are to, map and monitor fresh water and nutrient fluxes and pathways across the Pacific Gateway and into the Arctic Ocean, promote U.S. - Russian Federation and international cooperation in ocean and polar regions studies, and facilitate exploration and information gathering of this poorly mapped region of the climate system.

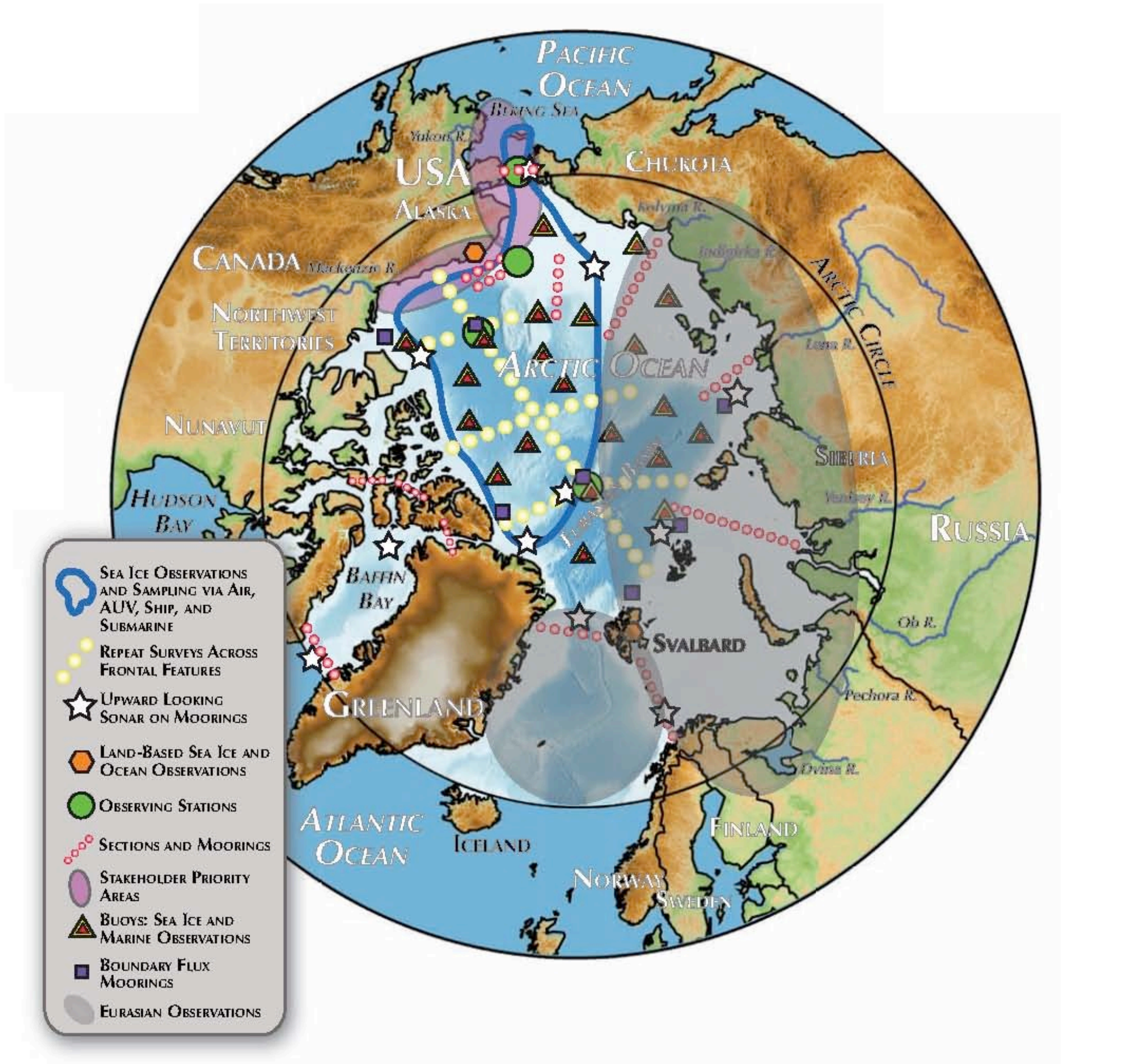


Figure 2. SEARCH priority areas for distributed ocean and sea ice observations. *The highest priority for SEARCH is long-term and large-scale observations of environmental change. Observation requirements include those related to physical/chemical ocean, geophysical sea ice, biological/chemical, and stakeholder-relevant variables; sensors and measurements should be co-located to the extent possible. Key regions include: Beaufort Gyre, North Pole, Bering Strait, Canadian Archipelago, and Eurasian Basin slopes and shelves; Alaska near-shore observations in the Bering, Chukchi and Beaufort Seas (stakeholder priority areas, purple shading); and the Chukchi/Beaufort shelf-slope area. Priority observation activities include: repeat hydrographic/tracer surveys across frontal features (yellow dotted lines) and sea ice and ocean sampling along transects (blue line) via ship, aircraft, AUVs, and submarine; boundary flux sections (red dotted lines, additional boundary flux moorings denoted by purple squares); drifting buoys for marine and sea ice measurements (yellow/red triangles); sea ice and ocean observations via land-based platforms (orange polygons) and upward-looking sonar (ULS) on moorings (white stars); and long-term observing stations (green dots). Eurasian observations (gray shaded areas) will focus on Arctic/Atlantic linkages, with some explicit U.S. collaborations assumed. The locations of all SEARCH sections, buoys, and moorings in this figure are meant only as general suggestions of deployment schemes.*

a. THE PACIFIC GATEWAY TO THE ARCTIC – QUANTIFYING AND UNDERSTANDING BERING STRAIT OCEANIC FLUXES. Russian American Long-term Census of the Arctic

Contact People: Rebecca Woodgate (UW), Tom Weingartner (UAF), Terry Whitledge (UAF)

The Bering Strait, a narrow (~ 85 km wide), shallow (~ 50 m deep) strait at the northern end of the Pacific, is the only ocean gateway between the Pacific and the Arctic. Although the flow through the strait is small in volume (~ 0.8 Sv northward in the annual mean), due to its remarkable properties (high heat and freshwater content, low density, high nutrients) it has a startling strong influence, not only on the Chukchi Sea and the Arctic Ocean, but also on the North Atlantic overturning circulation and possibly world climate. Draining the Bering Sea shelf to the south, the Bering Strait throughflow is an integrated measure of Bering Sea change. The comparatively warm, fresh throughflow contributes ~ 1/3rd of the freshwater input and possibly ~ 1/5th of the oceanic heat input to the Arctic, and provides the most nutrient-rich waters entering the Arctic Ocean.

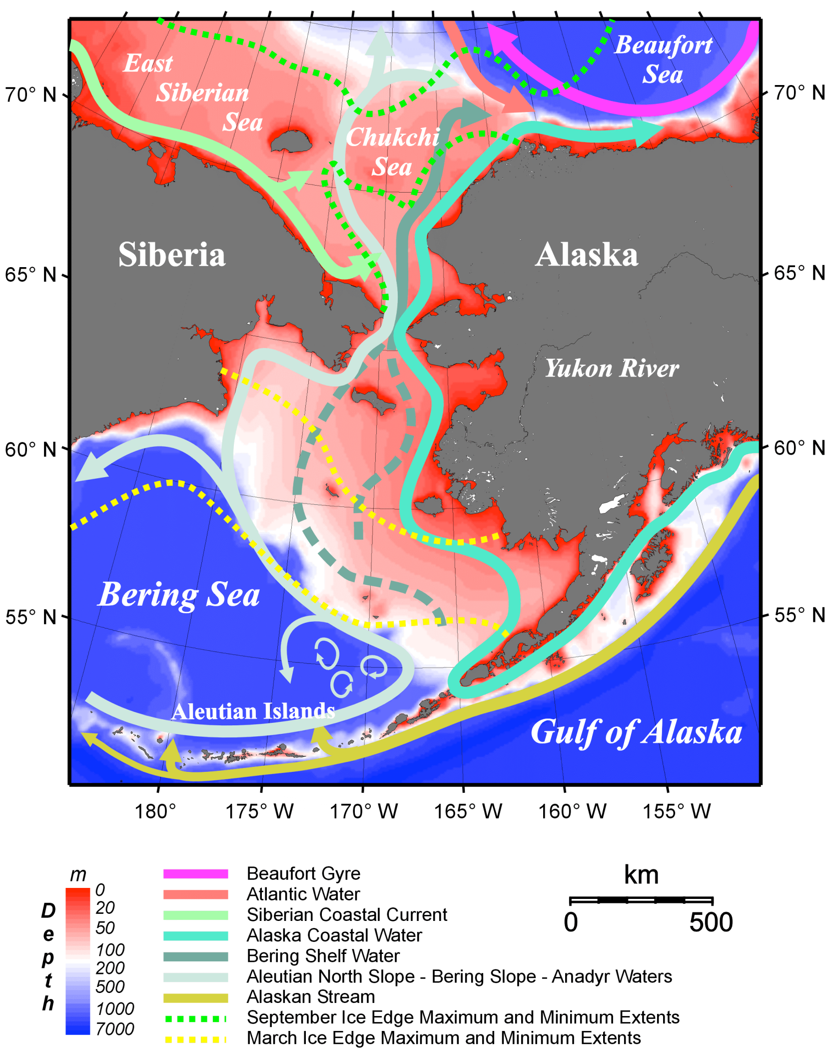
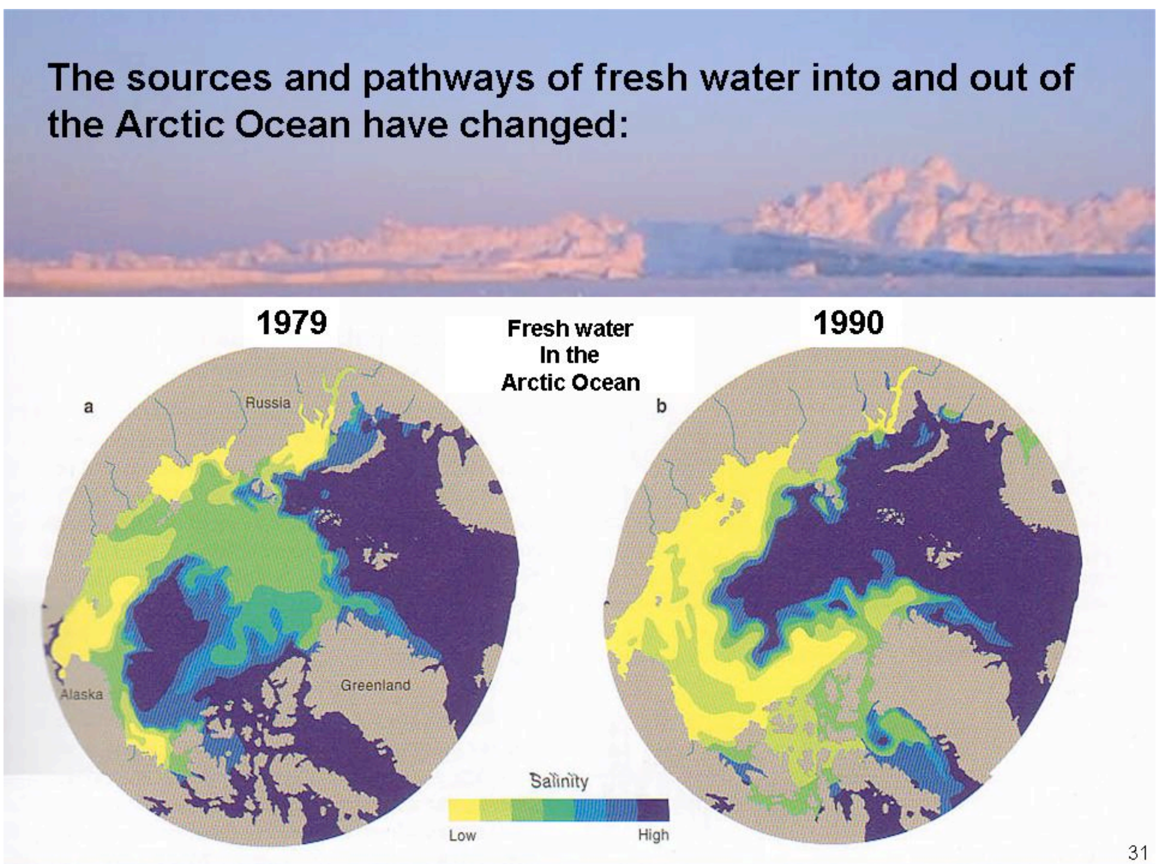


Illustration of the currents through the Bering Strait.

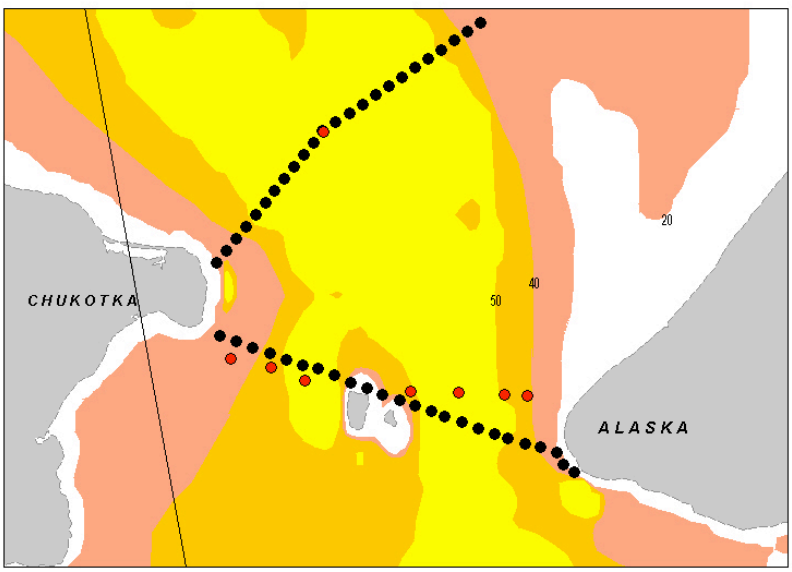
Furthermore, the low density of these waters keeps them high in the Arctic water column, giving them a key role in upper ocean ecosystems and physical processes including ice-ocean interactions. At the time when dramatic change, especially the retreat of sea-ice, is observed in the Bering and Chukchi seas and the Arctic, we have measured significant increases of Bering Strait fluxes of volume, freshwater and heat, the heat flux in 2004 being the maximum recorded in the last 15 years.

Yet, our understanding of what sets the properties and variability of the Bering Strait throughflow is still rudimentary. Indeed, our ability to measure these fluxes accurately has, in the past, been constrained by lack of data, both from the most nutrient-rich western half of the strait (which lies in Russian waters), and from the upper water column (due to potential ice-keel damage to instrumentation), where stratification and coastal boundary currents (especially the Alaskan Coastal Current in the eastern channel) contribute significantly to freshwater and heat fluxes.



More freshwater has been accumulating in the Pacific sector of the Arctic Ocean, *particularly since the 1990's. Low salinity (yellow). Transport pathways of water and ice across the Arctic have also changed significantly. The Bering Strait is on the left middle of the image.*

Furthermore, although recognized as a key ocean gateway by national and international global observing initiatives, there had still been no long-term observing strategy for the Bering Strait until the development of the RUSALCA program (Russian-American Long-term Census of the Arctic). Building on US-Russian collaborations established in 2004 and NOAA- NSF collaboration to build the critical observing chain of moorings in this Pacific - Arctic Gateway, The RUSALCA program undertook the first ever deployment of instrumentation in both the Russian and U.S. waters of the Bering Strait in August-September of 2007 onboard the Russian Naval hydrographic vessel "SEVER".



RUSALCA STATIONS, BERING STRAIT

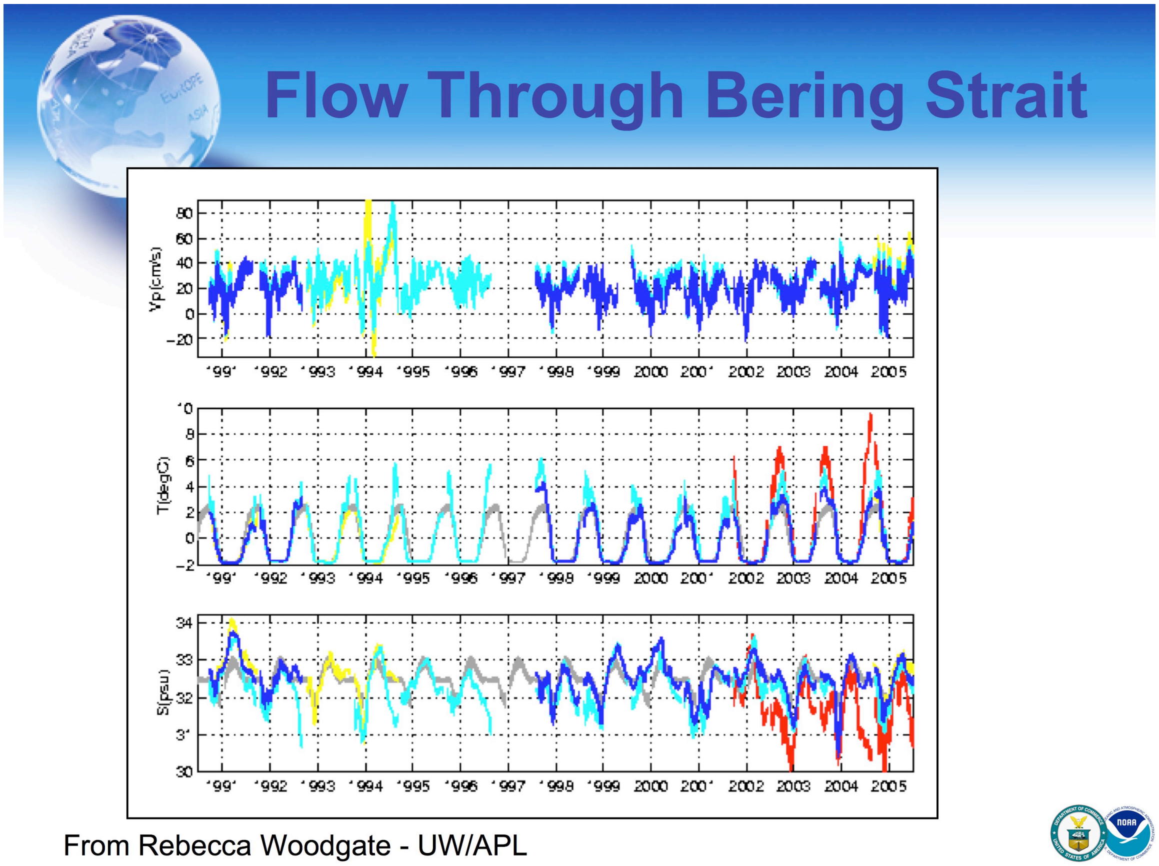
PROPOSED MOORING LOCATIONS

2007 mooring locations (red), CTD stations in black. Depth is in meters.

The science objectives are:

1) To measure the velocities and water properties of the Bering Strait throughflow;
2) To understand the physical processes influencing the properties of the Bering Strait throughflow, with special focus on mechanisms driving change, and impacts on the

Arctic Ocean;
 3) To quantify (or at least bound) oceanic fluxes of volume, freshwater, heat, nutrients, and chlorophyll biomass through the strait; and
 4) To design an optimum monitoring system for oceanic fluxes through the Bering Strait.



30-day running mean time-series of all available velocity, temperature, and salinity data from the Bering Strait mooring sites (Green) western channel, Russian Federation waters, (light blue) eastern channel (U.S. waters), (dark blue) north Bering Strait, (yellow) central Chukchi Sea and (red) base of the Alaskan Coastal Current. The background gray is a 15-year climatology for the central Chukchi Sea. Solid black lines are weekly averages of sea surface temperature from MODIS satellite data from the eastern channel. Prior to 2007 mooring operations in the western and eastern channels were not coordinated.

The hypotheses of the Principal Investigators in the RUSALCA program are that Bering Strait throughflow properties are set by global and regional oceanic and atmospheric processes, which are vulnerable to climate change; and that understanding the physical processes and scalings in the strait are key to quantifying current conditions, assessing future change scenarios, and designing an efficient observational scheme for this oceanic gateway.
 Additionally, the RUSALCA Bering Strait moorings will provide an observational platform for other Bering Strait measurements; an annually- updated status of Bering Strait fluxes and potential Arctic impacts for the science community and the general

public; and public dissemination of results and the importance of global oceanography to US schools and the general public, including via a Polar Science Weekend at the Pacific Science Center (Seattle's major science museum).

By quantifying and understanding oceanic fluxes at this key Pacific-Arctic ocean gateway, this work contributes directly to NOAA's mission of documenting the climate system and detecting change. The work also directly fulfils RUSALCA goals and milestones, specifically by quantifying Bering Strait fluxes of freshwater, heat and nutrients, via annual mooring data; by maintaining climate CTD lines in the Bering Strait and Chukchi Sea; and by providing annual updated estimates of fluxes (including data and data products) via a public website and national data archives.

CRUISE REPORT FOR BERING STRAIT MOORING PROJECT 2007

Russian Vessel SEVER ('North') – RUSALCA2007

Nome, 27th August 2007 – Nome, 5th September 2007

Rebecca Woodgate, University of Washington (UW),woodgate@apl.washington.edu

Funding from NSF ARC-0632154 and NOAA RUSALCA program. An International Polar Year Project

Science Coordinators: *Kathy Crane, NOAA, USA, Mikhail Zhdanov, Group Alliance, Russia (RF)*
Science Liaison at Sea: *Kevin Wood, NOAA/UW, USA, and Vladimir Smolin, State Research Navigational Hydrographical Institute (SRNHI), RF*
Chief Scientist: *Terry Whitledge, University of Alaska, Fairbanks (UAF), USA*
Lead for Mooring Team: *Rebecca Woodgate, UW, USA*

As part of the joint US-Russian RUSALCA (Russian US Long-term Census of the Arctic Ocean) Program, a team of US and Russian scientists undertook an oceanographic cruise in summer 2007 on board the Russian vessel 'Sever'. The cruise started in Petropavlosk, Russian Federation, on 22nd August. It arrived in Nome, USA, on the evening of 26th August. There, it picked up the US science team and equipment on 27th August, and sailed for the Bering Strait on 28th August. A major objective of the cruise was mooring work in the Bering Strait region (recovery of 7 moorings, deployment of 8 moorings), related high resolution CTD sections with nutrient sampling, and some benthic grab work. This cruise report concerns the mooring and physical CTD work - for details of other programs, please contact the Chief Scientist.

Cruise Participants

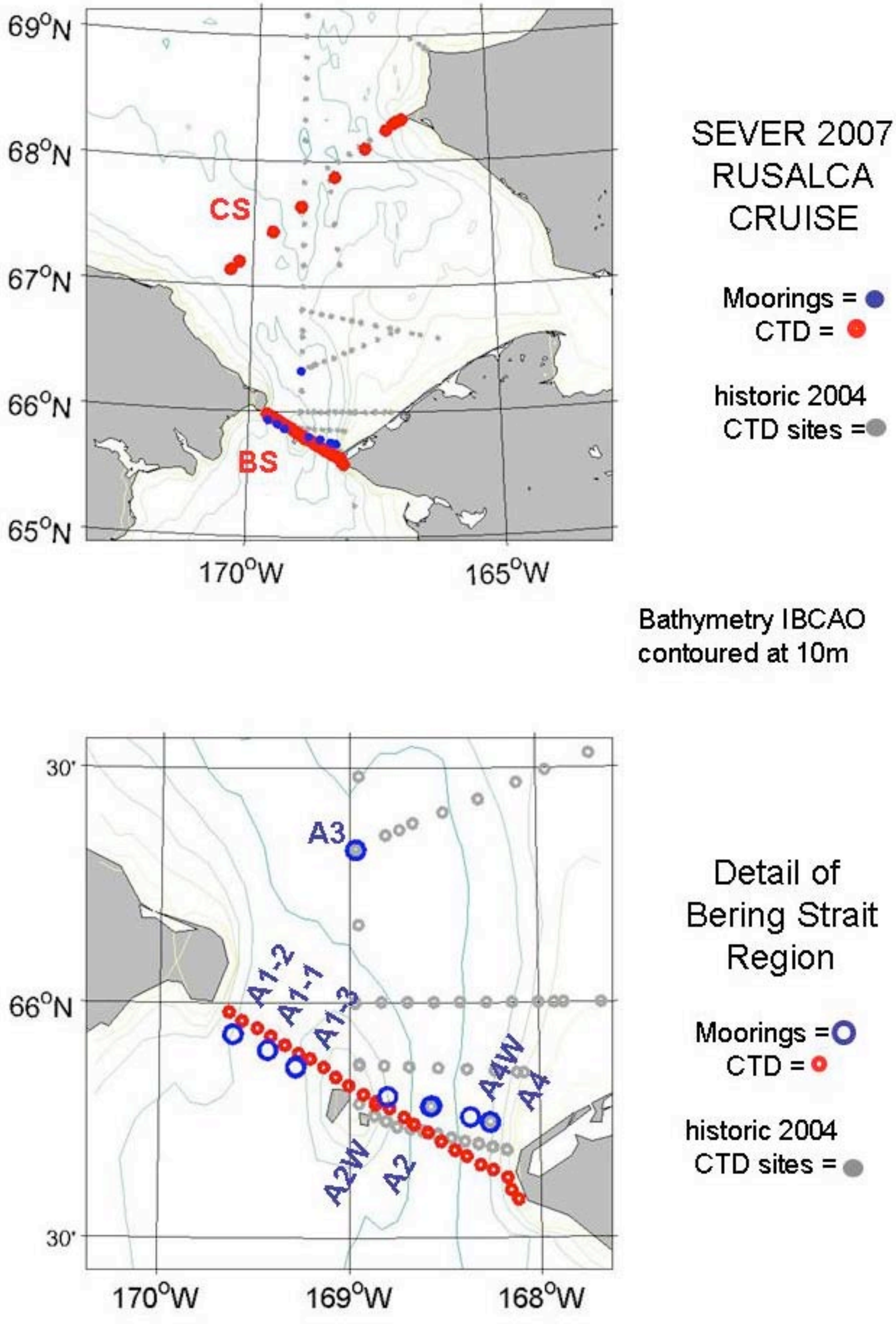
- US

1. Terry Whitedge (M), UAF, USA – *Chief Scientist, nutrients, moored nutrient sampler*
2. Kevin Wood (M), NOAA/UW – *Science Liaison*
3. Rebecca Woodgate (F), UW – *Moorings*
4. Jim Johnson (M), UW – *Moorings*

- Russian

5. Vladimir Smolin (M), SRNHI, RF – *Science Liaison and translator*
6. Igor Lukashenko (M), Pacific Hydrographic Service- *Vladimir's assistant*
7. Konstantin Bachinsky (M), Pacific Oceanography Inst, RF
8. Valerian Golavsky (M), Arctic and Antarctic Research Institute (AARI), RF – *Moorings*
9. Vladislav Djurinsky (M), Zoological Institute (ZIN) , RF – *Benthic work*
10. Vladislav Potin (M), ZIN, RF – *Benthic work*
11. Igor Karnaushevskiy (M), RF Ministry of Defense

Cruise Map of Stations relevant to UW Mooring work



*SEVER 2007 RUSALCA mooring (blue dots) and CTD (red dots) locations.
The Bering Strait (BS) line was run contiguously from east to west with a 7 hour break at the Diomede Islands in the centre of the strait (one station was repeated after this break). The Cape Serdtse Kamen to Point Hope (CS) line was run contiguously from east to west. Small grey dots mark CTD stations from the Bering Strait Alpha Helix cruise in 2004 [Woodgate, 2004].*

Contours from IBCAO every 10 m.
Cruise Time-schedule

Friday 24th Aug 2007 *mooring team arrive Nome.*

Saturday 25th Aug 2007 *prep mooring gear on shore in Nome.*

Sunday 26th Aug 2007 *prep mooring gear on shore in Nome, Sever docks in Nome in evening.*

Monday 27th Aug 2007 *loading, and mooring gear prep.*

Tuesday 28th Aug 2007 *cast off 8am, wait for freight, depart for Bering Strait pm, arrive at mooring site A1-3 ~ 10pm local time, recover A1-3-06.*

Wednesday 29th Aug 2007 *recover A1-1-06, fog at A1-2-06, deploy A1-1-07, wait out fog at A1-2-06, recover A1-2-06, deploy A1-3-07.*

Thursday 30th Aug 2007 *deploy A1-2-07, recover A2-06, recover A4-06, steam to A3-06.*

Friday 31st Aug 2007 *recover A3-06, deploy A3-07, deploy A2-07, deploy A2W-07, shelter over night on west side of strait.*

Saturday 1st Sep 2007 *deploy A4W-07, deploy A4-07, prep CTD gear, run half of BS line from east to the Diomede Islands (station BS12).*

Sunday 2nd Sep 2007 *continue BS line after 7hr break, redoing BS12, download data.*

Monday 3rd Sep 2007 *run CS line with mud sampling from east to west, not quite finishing line by midnight. Leave for Nome around midnight.*

Tuesday 4th Sep 2007 *data transfer and backup, packing, dock Nome ~8pm.*

Wednesday 5th Sep 2007 *offload, Sever leaves for Petropavlosk ~ 3pm, mooring team leaves Nome.*

Total: 8 days at sea,

Background to mooring and CTD program

Moorings: The moorings serviced on this cruise are part of a multi-year time-series (started in 1990) of measurements of the flow through the Bering Strait. This flow acts as a drain for the Bering Sea shelf, dominates the Chukchi Sea, influences the Arctic Ocean, and can be traced across the Arctic Ocean to the Fram Strait and beyond. The long-term monitoring of the inflow into the Arctic Ocean via the Bering Strait is important for understanding climatic change both locally and in the Arctic. Data from 2001 to 2004 suggest that heat and freshwater fluxes are increasing through the strait [*Woodgate et al.*, 2006]. The work completed this summer should tell us if this is a continuing trend.

An overview of the Bering Strait mooring work (including access to mooring and CTD data) is available at http://psc.apl.washington.edu/BeringStrait.html.

Six moorings were recovered on this cruise.

-- Three moorings (A2-06, A3-06, A4-06 in US waters) were deployed under an Alaskan Ocean Observing System (AOOS, http://www.aoos.org) grant to *Woodgate and Weingartner*.

-- The other three moorings (A1-1-06, A1-2-06, A1-3-06) were a joint US-Russian (*Weingartner and Lavrenov*) project, part of the NOAA-led RUSALCA (Russian-American Long-term Census of the Arctic, http://www.arctic.noaa.gov/aro/russian-american/) program.

A total of 8 moorings (in Russian waters – A1-1-07, A1-2-07, A1-3-07, in US waters – A2W-07, A2-07, A4W-07, A4-07, A3-07) were deployed in another joint US-Russian venture supported by RUSALCA and by NSF-OPP (*Woodgate, Weingartner, Whitledge, Lindsay, NSF-OPP-ARC-0632154*).

This is the highest resolution array ever deployed in the Bering Strait, (see map above). Three moorings were deployed across the western (Russian) channel of the strait (from west to east - A1-2-07, A1-1-07, A1-3-07). Four moorings were deployed across the eastern (US) channel of the strait (from west to east - A2W-07, A2-07, A4W-07, A4-07). A final 8th mooring (A3-07) was deployed ca. 35 nm north of the strait at a site proposed as a "climate" site, hypothesized to measure a useful average of the flow through both channels [*Woodgate et al.*, 2007]. Testing this hypothesis is a main aim of this work. All moorings measure water velocity, temperature and salinity near bottom (as per historic measurements). Additionally, 6 of the 8 moorings (i.e., all eastern channel moorings, the climate site mooring A3, and the mooring central in the western channel) also carried upward-looking ADCPs (measuring water velocity in 1-2 m bins up to the surface, ice motion, and medium quality ice-thickness) and ISCATS (upper level temperature-salinity-pressure sensors in a trawl resistant housing designed to survive impact by ice keels). Bottom pressure gauges were also deployed on the moorings at the edges of the eastern channel (A2W-07 and A4-07). (The preferred locations – A1-2-07 and A4-07 – were unavailable.) Two moorings (A2-07, central eastern channel; and A1-2, western part of western channel) also carried ISUS nitrate sensors and optical sensors for fluorescence and turbidity. Recovered moorings in the central eastern channel and at the climate site (A2-06 and A3-06) carried Upward Looking Sonars (ULSs) measuring high-quality sea-ice thickness. These instruments were not redeployed. For a full instrument listing, see the table below.

This coverage should allow us to assess year-round stratification in the strait and also to study the the physics of the Alaskan Coastal Current, a warm, fresh current present seasonally in the eastern channel, and suggested to be a major part of the heat and freshwater fluxes [*Woodgate and Aagaard*, 2005; *Woodgate et al.*, 2006]. The current meters and ULSs allow the quantification of the movement of ice and water through the strait. The nutrient sampler, the transmissometer and fluorometer time-series measurements should advance our understanding of the biological systems in the region.

CTD: The moorings are supported by annual CTD sections, with water samples for nutrients. The best coverage achieved to date was in 2004 from the Alpha Helix, although that cruise was limited to US waters. For reference, the 2004 Helix stations are indicated as small grey dots on the map above. The most important section is the high resolution CTD section run across the Bering Strait (named BS). This was completed in 2007 and included both US and Russian waters. There are two other lines which we attempt to maintain during this cruise. One (named CS) is a coast-to-coast section with high resolution near the coasts running from Cape Serdtse Kamen (RF) to Point Hope (US) – part of that line was completed during this 2007 cruise. The other is a high resolution line through mooring site A3 – this line was not taken during this 2007 cruise.

International links: Maintaining the time-series measurements in Bering is important to several national and international programs, e.g. NSF's Freshwater Initiative (FWI) and Arctic Model Intercomparison Project (AOMIP), and the international Arctic SubArctic Ocean Fluxes (ASOF) program. The mooring work also supports regional studies in the area, by providing key boundary conditions for the Chukchi Shelf/Beaufort Sea region; a measure of integrated change in the Bering Sea, and an indicator of the role of Pacific Waters in the Arctic Ocean. Furthermore, the Bering Strait inflow may play a role in Arctic Ocean ice retreat and variability (especially in the freshwater flux) is considered important for the Atlantic overturning circulation and possibly world climate [*Woodgate et al.*, 2005].

Mooring Operations during 2007 Sever cruise

Despite fog and certain challenges (see below), the mooring work was successfully completed. The acoustic hydrophone was deployed via the window in the aft lab. Once the mooring was released, the ship brought the floating mooring along the port side, where it was grappled by hook and brought aboard onto the foredeck using the Sever's substantial forward crane. The following issues are noteworthy:

1) On two moorings (A3-06 and A4-06), barnacles jammed the mechanism on the releases. In both cases, this problem was limited to one release of the double releases used, and thus the mooring was successfully released with the second release. In both cases, the drop link remained attached to the jammed release and was only freed on deck, in the A3 case by tugging the release and in the A4 case by chipping at the barnacle. These moorings had been in the water since July 2006, i.e., through two growing seasons). To prevent this, ***antifouling should be used on critical parts of the release mechanism.***

2) Several of the releases were found to require a special deckset, since a manufacturer's error made the acoustic circuits temperature dependent. With this deckset, codes normally starting with 4 can be retuned by changing the initial digit of the code. All recoveries except A1-3 (which had an older release) required this special deckset. For successful communication, by trial and error, the following pattern for the initial digit was found (relating somewhat to temperature) – A1-1-06 required 8, A1-2-06 required 8, A2-06 required 8, A4-06 required 9, A3-06 required 8 or 9 depending on the release. It was necessary to redeploy some of these releases – thus, ***for 2008, moorings A1-2-07 and A1-3-07 will require the special deckset.***

3) Release sn 32426 (recovered from A1-2-06 and redeployed on A1-2-07) was reported with the wrong enable code. The correct code is 474043 (with the first digit altered to 8 for the temperature dependence problem discussed above).

4) Although the weather was in general calm, fog delayed mooring recoveries in the western parts of the western channel, especially A1-2-06. It would be interesting to relate this to water properties.

5) The moorings in the eastern channel and at the northern site were deployed last summer (as compared to the autumn deployment of the western channel moorings) and showed significantly more biofouling than instrumentation in the western channel. This likely reflects the longer deployment period, and possibly warmer waters. Barnacles up to 3 cm were common on these moorings – barnacle growth has becoming the dominant form of biofouling in the strait in recent years. Unusually small barnacles were also found on the lower parts of the release mechanisms. Other than impeding the release mechanism, it does not yet seem that the data is degraded by the biofouling. In all cases, salinity cells remained clear. A future recommendation is to use anti-fouling measures on the releases.

Very preliminary analysis of the mooring data show very good data return, apart from one flooded microcat (temperature, salinity instrument) on the eastmost mooring (A4). Some instruments – ULSs (Upward Looking Sonars, measuring ice thickness), and the AARI current meter and CTD – could not be downloaded at sea, but are expected to be read on return to their institutes.

The data show the usual large annual cycle in temperature and salinity. Many of the usual features are present, i.e. high variability in autumn, generally with freshening and cooling; salting (at the freezing point) in the winter; freshening and warming in the spring [*Woodgate et al.*, 2005]. Interestingly in the spring 2007 warming, A2 is distinctly colder than the western channel data – this unusual situation requires further investigation, as do the strong warming events at A2 in the warmest period of 2006. A more detailed analysis is necessary to seek for interannual signals. Also noteworthy is the persistence of northward flow for the last ~ 3 months of the record (i.e. summer 2007). The flow through the strait is believed to be driven by a sea-level difference between the Pacific and the Arctic, which drives a flow northwards towards the Arctic. Local winds (usually southward in the annual mean) tend to oppose this flow and may reverse it on timescales of days [*Woodgate et al.*, 2005b]. However, the recovered data suggest that reversals have been unusually uncommon this summer. (This is consistent with verbal reports from Nome about the extreme clemency of the weather.) Since the variability of northward fluxes of heat and freshwater are dominantly dependent on the variability of the volume transport [*Woodgate et al.*, 2006], this may imply further increases in this fluxes, with possible implications for the Arctic and beyond.

Details of mooring positions and instrumentation are given below, along with schematics of the moorings, photos of the mooring fouling and preliminary plots of the data.

CTD Operations during 2007 Sever cruise

Due to clearance issues, the 2007 cruise sailed without a UAF mooring technician. Lack of personnel delayed the mooring and limited the CTD sections which could be taken. Of the proposed 3 CTD lines, one (the Bering Strait line BS) was completed from east to west with a 7hr break during the run, and one (the Cape Serdtse Kamen line CS) was roughly 3/4 completed from east to west.

Two internally sampling CTDs (an SBE25 and an SBE19) were deployed strapped together from the upper deck winch on the starboard aft deck. In addition CTD, the SBE 19 also recorded oxygen, fluorescence, and PAR. At each station up to three bottle samples were taken – nominally surface (by bucket), bottom and midwater column (by niskin). The bottom niskin was suspended ~ 2 m below the CTD on a bottom trip mechanism. The mid-water bottle was attached to the wire during the downcast and closed by messenger when the cast was estimated to be at the bottom. Bottom depths were estimated from the bridge depth sounder. On station 19, the CTD hit bottom, but mostly the cast did not appear to hit bottom. The table below gives CTD positions, LOCAL times (for GMT, add 8 hrs), estimated depth from the bridge depth sounder, and depth to which the CTD was lowered (calculated by wire out). The bottom bottle is likely from ~ 2 m deeper than the maximum CTD pressure (likely the MaxP here, but this should be checked against the CTD records). An estimate of the mid-water bottle depth is also given from wire out. This could also be extracted from the CTD data since the CTD cast was stopped to attach and remove the bottle.

Preliminary CTD sections are given below. These should be treated with caution as they are (a) blindly 1-m binned and (b) based on pre-calibrations.

Table of Bering Strait Mooring Positions (US GPS) and Instrumentation

ID	**LATITUDE (N)**	**LONGITUDE (W)**	**WATER DEPTH /m (corrected)**	**INST.**
RECOVERIES				
- Russian EEZ				
A1-1-06	65 54.000	169 25.783	50.5	ADCP, SBE37
A1-2-06	65 55.982	169 36.856	50.5	AARI, ISUS, SBE/TF, RCM9T
A1-3-06	65 51.764	169 16.956	50.5	AARI, RCM7, SBE37
- US EEZ				
A2-06	65 46.775	168 34.471	56	ULS, RCM9LW SBE/TF, ISUS
A3-06	66 19.543	168 58.009	58	ULS, RCM9LW SBE37

A4-06	65 44.73	168 15.67	49	ADCP, SBE37
DEPLOYMENTS				
- Russian EEZ				
A1-1-07	65 53.994	169 25.877	52	ISCAT, ADCP, SBE37
A1-2-07	65 56.019	169 36.763	53.3	ISUS, SBE/TF, RCM9T
A1-3-07	65 51.908	169 16.927	49	AARI, RCM9LW, SBE37
- US EEZ				
A2W-07	65 48.07	168 47.95	52	ISCAT, ADCP, SBE16, BPG
A2-07	65 46.87	168 34.07	56	ISCAT, ADCP, SBE/TF, ISUS
A4W-07	65 45.42	168 21.95	54	ISCAT, ADCP, SBE16
A4-07	65 44.77	168 15.77	50	ISCAT, ADCP, SBE16, BPG
A3-07	66 19.60	168 57.92	58	ISCAT, ADCP, SBE37

AARI = AARI Current meter and CTD
ADCP = RDI Acoustic Doppler Current Profiler
BPG=Seabird Bottom Pressure Gauge
ISCAT = near-surface Seabird TS sensor in trawl resistant housing, with near-bottom data logger
ISUS= Nutrient Analyzer
RCM7 = Aanderaa Mechanical Recording Current Meter
RCM9LW = Aanderaa Acoustic Recording Current Meter
RCM9T = Aanderaa Acoustic Recording Current Meter with Turbidity
SBE/TF = Seabird CTD recorder with transmissometer and fluorometer
SBE16 = Seabird CTD recorder
SBE37 = Seabird Microcat CTD recorder
ULS = APL Upward Looking Sonar

Table of Bering Strait CTD Positions (US GPS)

SEVER 2007 CTD POSITIONS - *recreated from written logs, start and endpositions also available*

 # Name US Date Time LOCAL Lat (N) &Long (W) at Bot WD MaxP MB
year mon day in bottom out Deg min Deg min /m /m /m

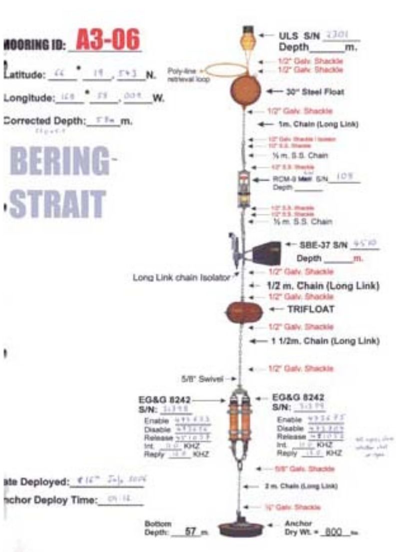
1 BS24 2007 9 1 1828 1834 1836 65 34.897 168 07.09 25 *23 13*
2 BS23 2007 9 1 1858 1902 1904 65 36.12 168 009.308 31 *26 11*
3 BS22 2007 9 1 1940 1942 1944 65 37.68 168 10.399 33 *29 14*
4 BS21 2007 9 1 *2042** 2044 2046 65 38.66 168 14.905 43 *39 19*
5 BS20 2007 9 1 2109 2113 2115 65 39.305 168 18.839 46 *42 19*
6 BS19 2007 9 1 2149 2153 2204 65 40.438 168 23.156 53 *49 24*
7 BS18 2007 9 1 2225 2229 2231 65 41.212 168 26.877 53 *49 24*
8 BS17 2007 9 1 2254 2258 2300 65 42.316 168 31.199 56 *52 27*
9 BS16 2007 9 1 2326 2330 2332 65 43.491 168 35.273 53 *49 24*
10 BS15 2007 9 1 2357 0001 0003 65 44.48 168 39.683 53 *49 24*
11 BS14 2007 9 2 0028 0032 0034 65 45.426 168 42.797 52 *48 23*
12 BS13 2007 9 2 0101 0106 0108 65 46.593 168 47.359 52 *48 23*
13 BS12 2007 9 2 0126 0130 0132 65 47.406 168 51.667 46 *42 17*
14 BS12 2007 9 2 0926 0929 0931 65 47.038 168 51.714 46 *42 17*
redone after 2am-9ambreak
15 BS11 2007 9 2 0952 0956 0958 65 48.338 168 55.559 47 *43 18*
16r BS10 2007 9 2 1029 1033 1035 65 49.474 169 00.206 41 *38.5 18*
17r BS9 2007 9 2 1057 1101 1102 65 50.549 169 04.304 46 *43.5 18*
18r BS8 2007 9 2 1124 1127 1129 65 51.832 169 08.155 46.5 *43 19*
19r BS7 2007 9 2 1241 1245 1247 65 52.903 169 12.426 49 *45 21*
hit bottom, brought up 2 sea-urchins
20r BS6 2007 9 2 1311 1315 1317 65 53.577 169 16.039 49 *45 21*
strumming, significant wire angle
21r BS5 2007 9 2 1344 1347 1349 65 54.653 169 20.429 50 *47 23*
strumming, green/brown water
22r BS4 2007 9 2 1420 1424 1426 65 55.77 169 24.86 53 *49 25*
water very brown
23r BS3 2007 9 2 1454 1458 1500 65 56.787 169 29.151 52.5 *49 25*
lots of propwash, discharge off deck, foggy
24r BS2 2007 9 2 1537 1541 1542 65 57.721 169 33.983 51 *47 23*
foggy
25r BS1 2007 9 2 1606 1610 1612 65 58.837 169 38.073 50 *46 22*
foggy, but warmer and calmer

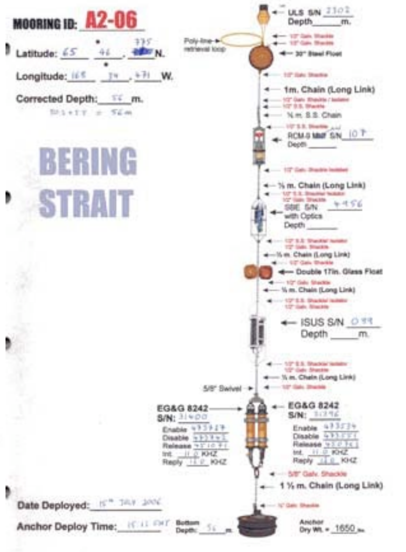
26M CS19 2007 9 3 1059 1102 -1104 68 19.975 166 52.112 27.5 *24 -*
27 CS18 2007 9 3 1129 1132 1133 68 19.047 166 57.801 34.5 *31 -*
jellyfish
28M CS17 2007 9 3 1155 1159 1200 68 18.075 167 02.69 39 *36 16*
29 CS16 2007 9 3 1251 1255 1257 68 15.029 167 11.927 44.5 *41 17*
30M CS14 2007 9 3 1421 1425 1427 68 6.126 167 39.85 53 *48 24*
31M CS12 2007 9 3 1634 1639 1641 67 52.501 168 18.799 57 *54 30*
32rM CS10 2007 9 3 1854 1858 1900 67 38.088 169 00.782 51 *47 23*
33rM CS8 2007 9 3 2054 2058 2100 67 25.976 169 35.985 50 *46 22*
34rM CS6 2007 9 3 2313 2317 2319 67 11.448 170 17.163 47.5 *44 20*
35rM CS5.5 2007 9 4 0001 0005 0007 67 7.646 170 27.585 46 *42 19*

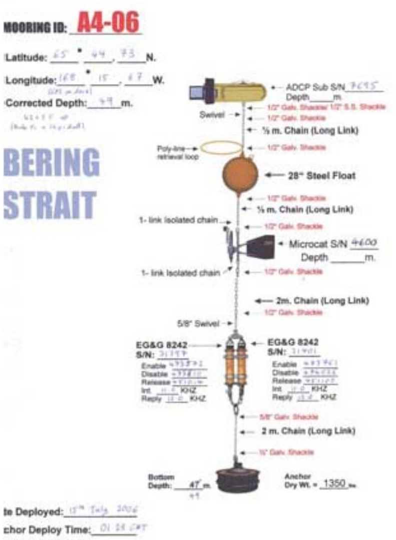
M=Mud samples were taken by Russian team. WD=water depth estimated by bridge. MaxP=distance CTD lowered from surface (bottom bottle ~ 2m deeper than this); MB=wire-out estimate of depth of middle bottle. *=estimated. r=in Russian EEZ.

SCHEMATICS OF MOORING RECOVERIES

= in US waters (AOOS moorings)



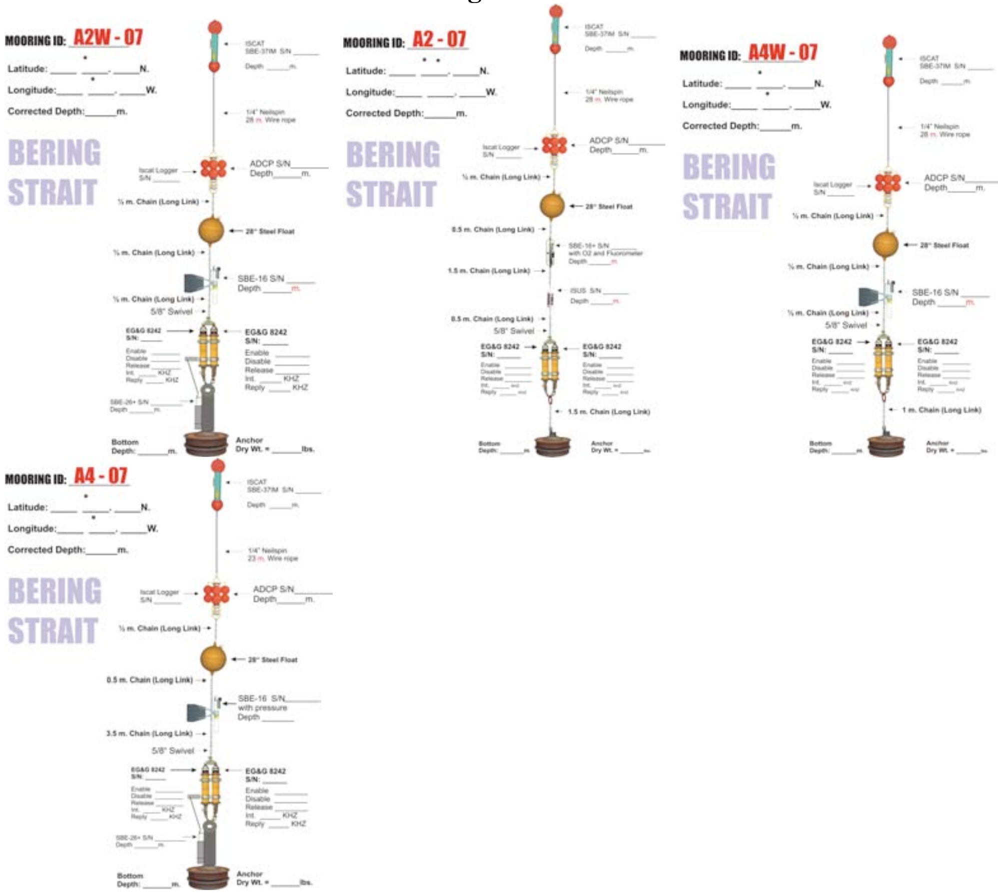




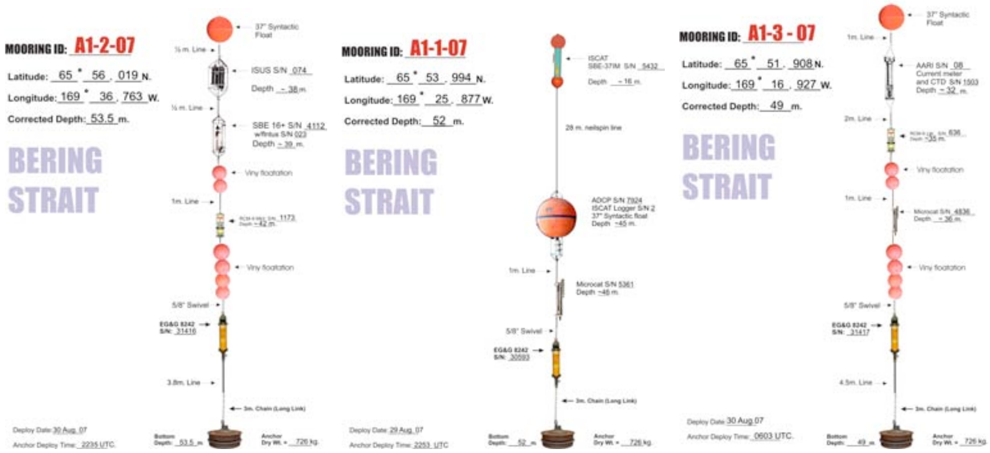
= in Russian waters (RUSALCA moorings)

SCHEMATICS OF MOORING DEPLOYMENTS

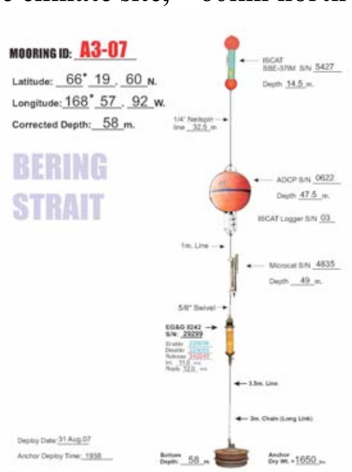
= in the eastern channel of the Bering Strait



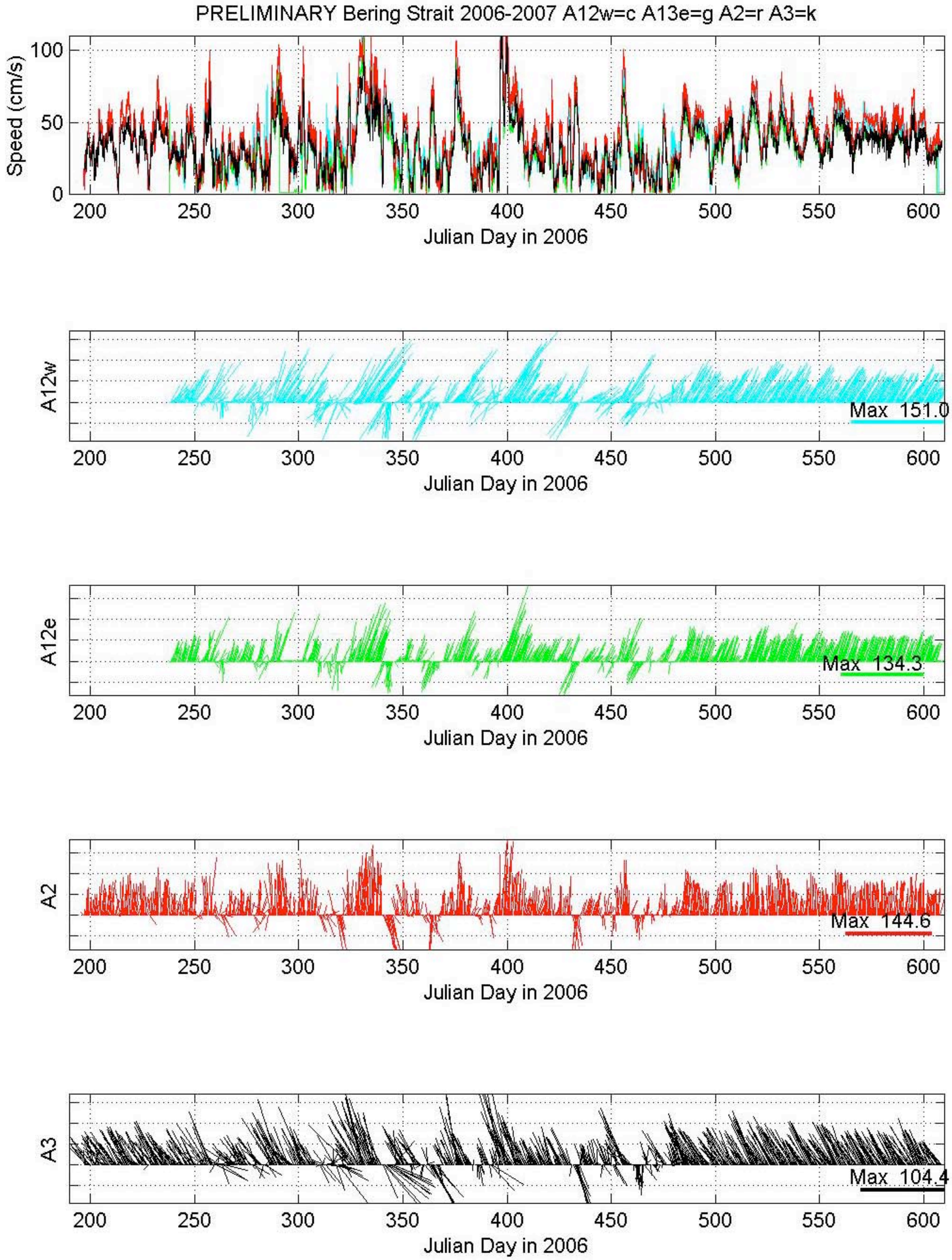
= in the western channel of the Bering Strait



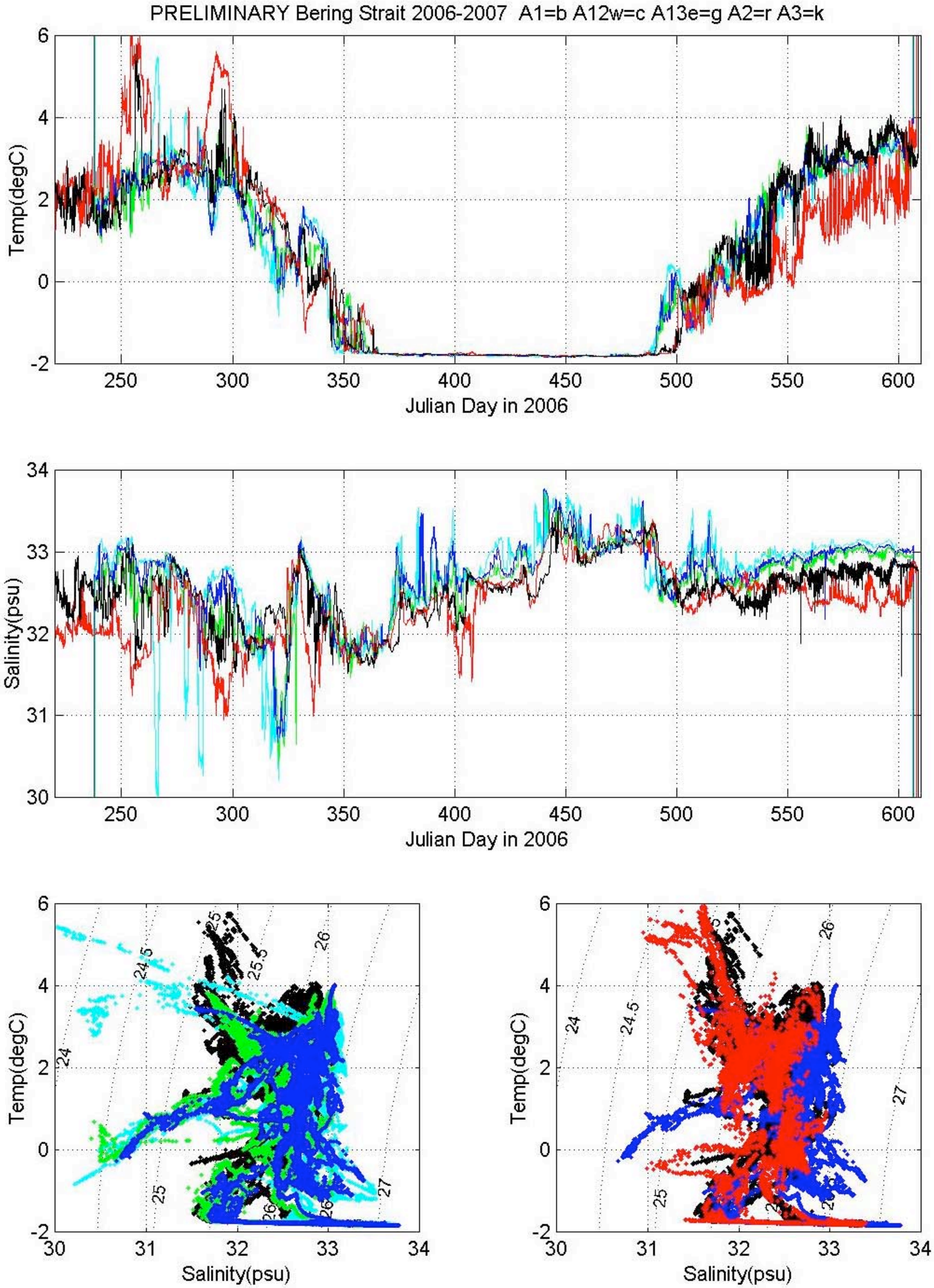
= at the climate site, ~ 60km north of the Strait



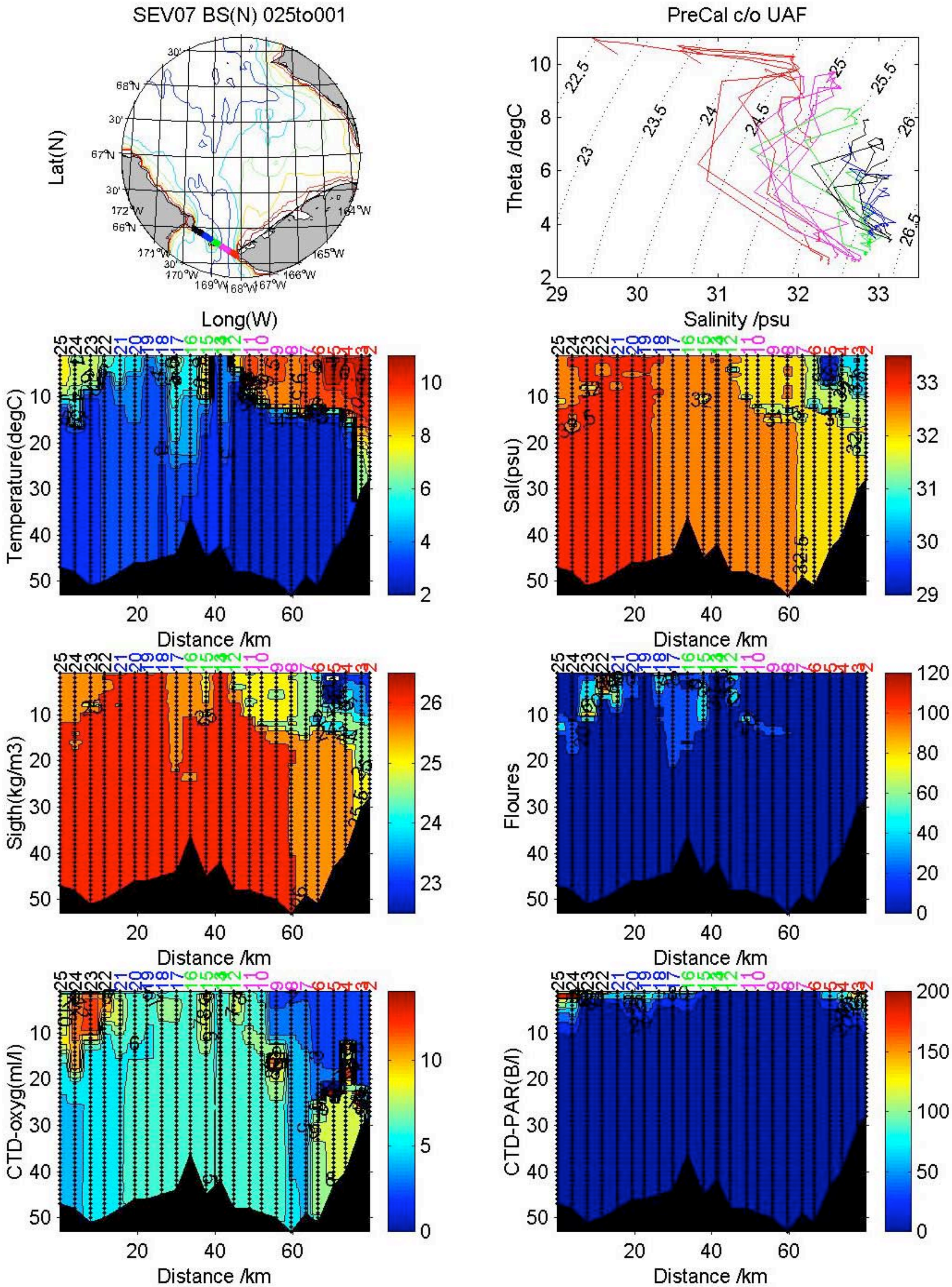
PRELIMINARY CURRENT METER RESULTS



PRELIMINARY SEACAT RESULTS

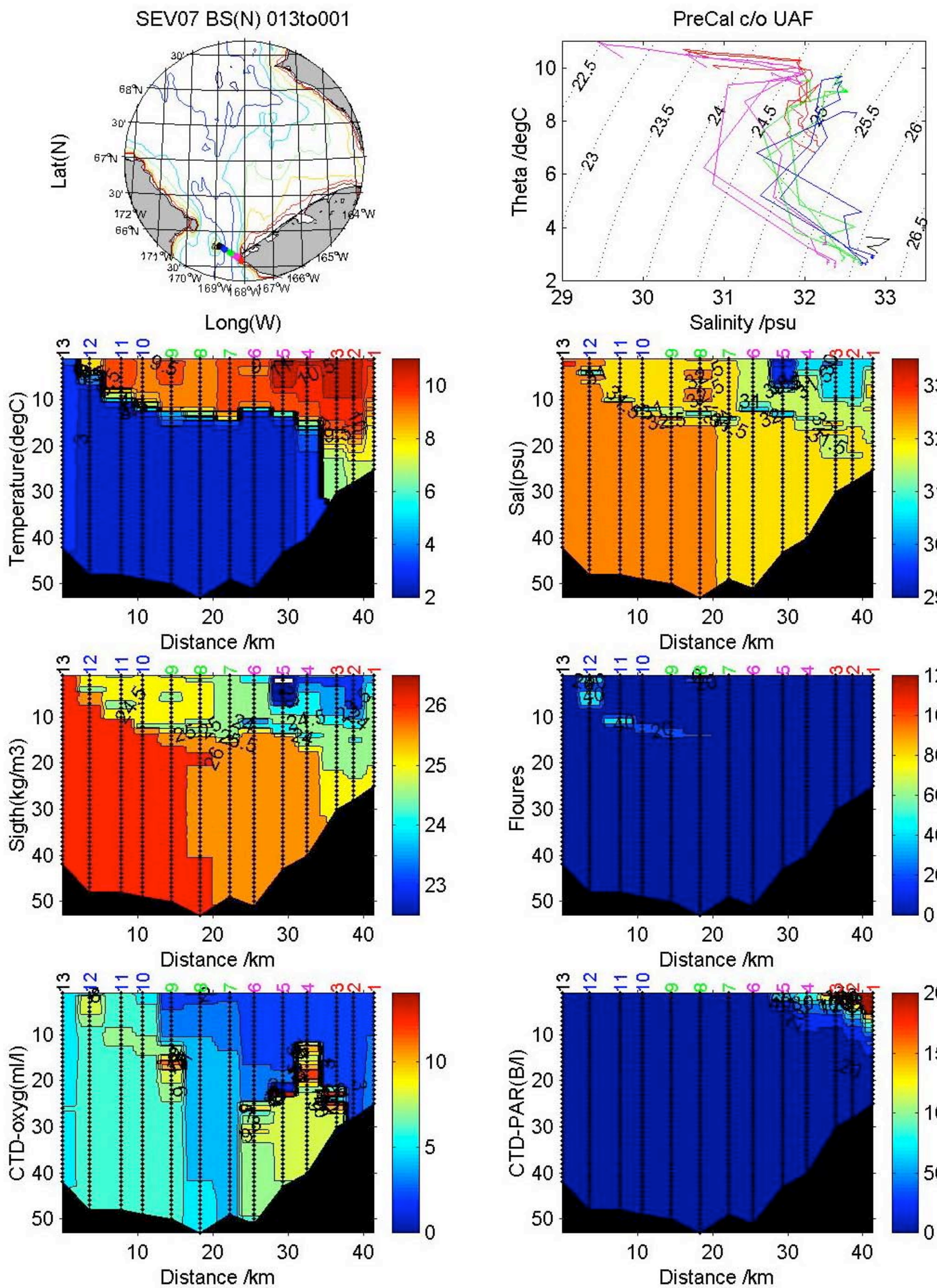

PRELIMINARY Bering Strait 2006-2007 A1=b A12w=c A13e=g A2=r A3=k
Temp(degC)
Julian Day in 2006
Salinity(psu)
Julian Day in 2006
Temp(degC)
Salinity(psu)
Temp(degC)
Salinity(psu)

PRELIMINARY CTD SECTIONS - BERING STRAIT (whole section, except cast 1)

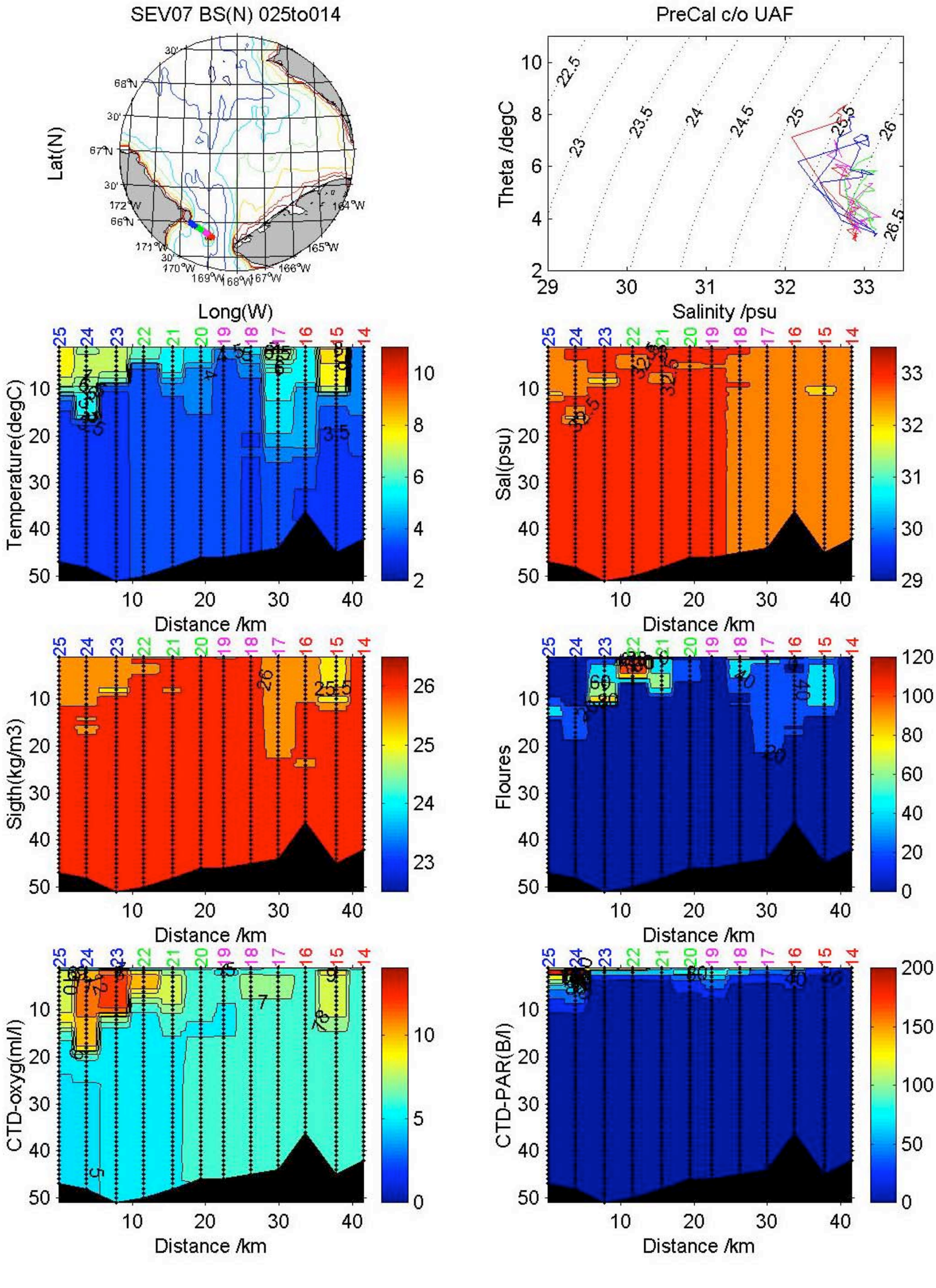


SEV07 BS(N) 025to001
PreCal c/o UAF
Lat(N)
Long(W)
Theta /degC
Salinity /psu
Temperature(degC)
Sal(psu)
Sigth(kg/m3)
Floures
CTD-oxyg(ml/l)
CTD-PAR(B/l)
Distance /km

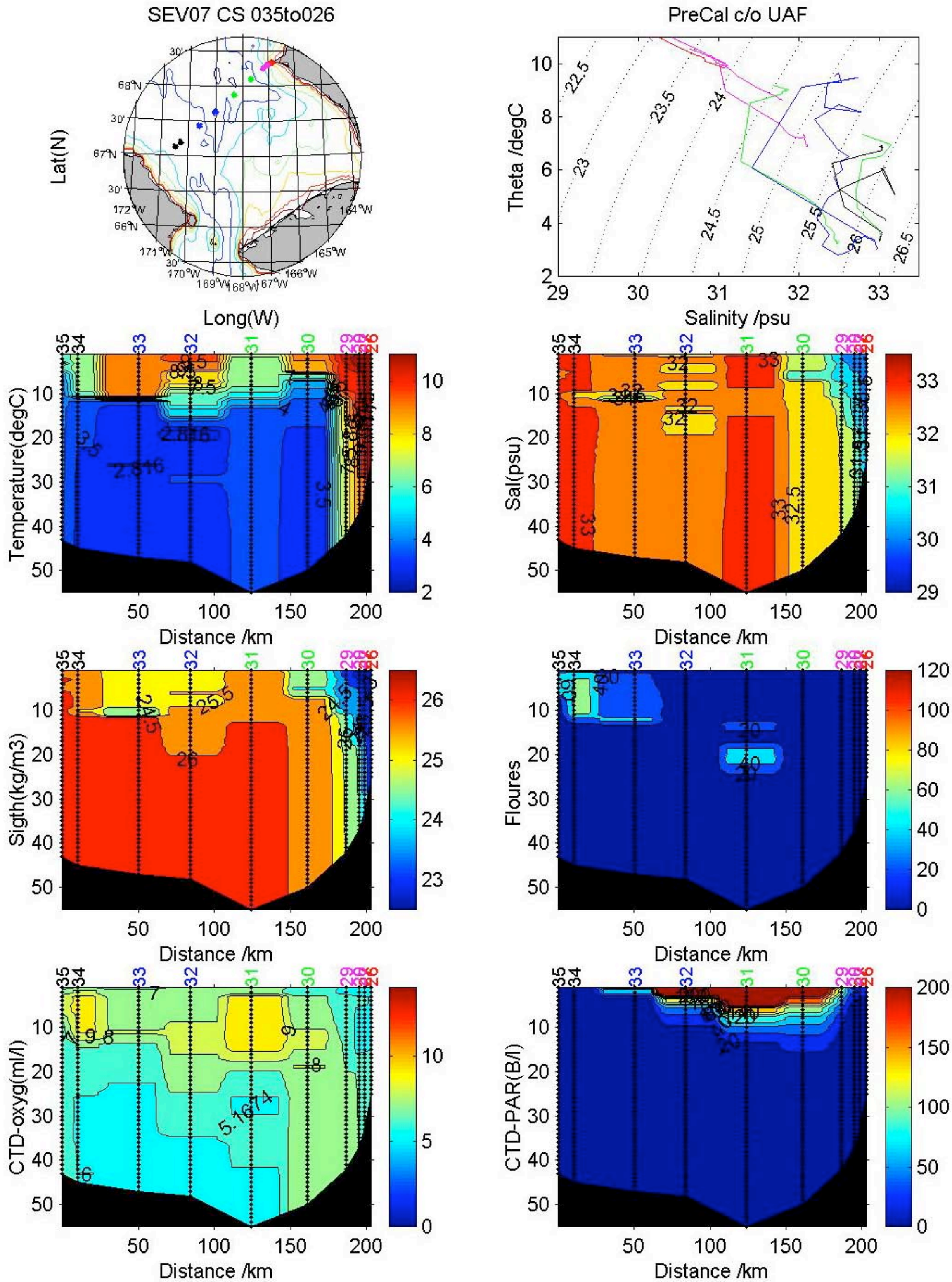
PRELIMINARY CTD SECTIONS - BERING STRAIT (eastern channel)



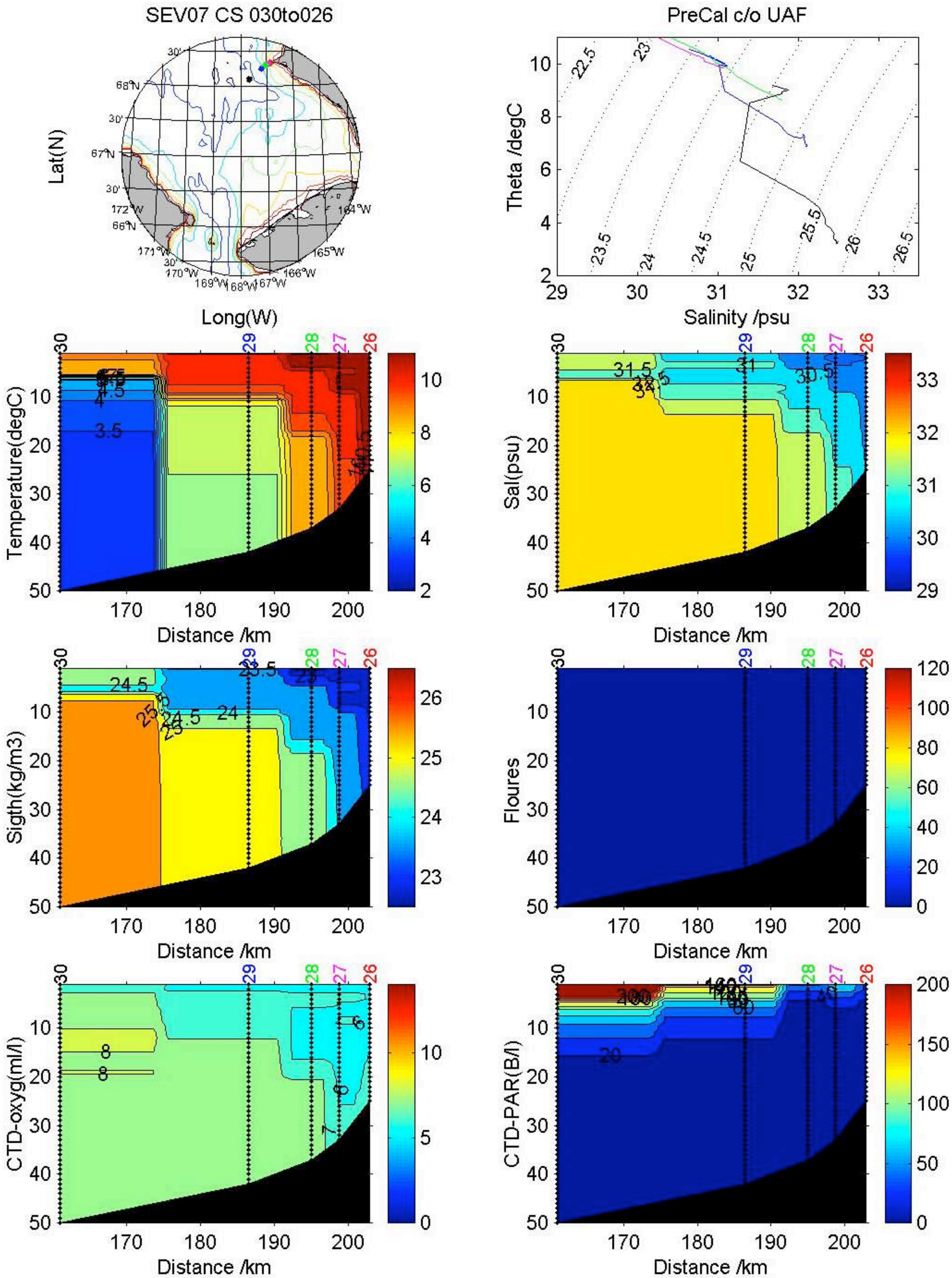
PRELIMINARY CTD SECTIONS - BERING STRAIT (western channel)



PRELIMINARY CTD SECTIONS - CAPE SERDTSE KAMEN to POINT HOPE LINE



PRELIMINARY CTD SECTIONS - CAPE SERDTSE KAMEN to POINT HOPE LINE (eastern end)



SEV07 CS 030to026
PreCal c/o UAF
Lat(N)
Long(W)
Theta /degC
Salinity /psu
Temperature(degC)
Sal(psu)
Sigth(kg/m3)
Floures
CTD-oxyg(ml/l)
CTD-PAR(B/l)
Distance /km

REFERENCES

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Woodgate, R. A., K. Aagaard, and T. J. Weingartner (2007), FIRST STEPS IN CALIBRATING THE BERING STRAIT THROUGHFLOW: Preliminary study of how measurements at a proposed climate site (A3) compare to measurements within the two channels of the strait (A1 and A2). 20 pp, University of Washington.

b. NABOS 07 Expedition in the Eurasian Basin Aboard the R/V Buynitskiy
Contact Person Igor Polyakov, IARC

The Arctic Research Program also managed an earmark to the International Arctic Research Center for the NABOS program. The 2007 field season for NABOS was difficultdue to problems with chartering the nuclear icebreaker Yamal. The NABOS scientist chartered a small ice-class research vessel Viktor Buynitsky from the Murmansk Roshydromet. The expedition proceeded into the Laptev, East Siberian and Barents Seas due to the anomalous ice-free conditions. The team successfully recovered two deep-water moorings and deployed five moorings, thus providing long-term stationary observations at key locations of the Arctic Ocean. The oceanographic cross-sections and extensive biochemistry and turbulence observations complemented mooring-based measurements. These observations showed that the exceptional warming which entered the Eurasian Basin in 1999 progressed from the Fram Strait along the Barents and Laptev slopes and was captured by conductivity/temperature/depth (CTD) cross-sections in the East Siberian Sea approaching Alaska's backyard. Observations during this cruise also documented strong warming of the very uppermost layer in the eastern Eurasian and Makarov basins. The magnitude of this warming is unprecedented in the history of regional instrumental observations. The unique strength and spatial distribution of this warm surface anomaly suggests the important role of oceanic heat in shaping the 2007 reduced Arctic Ocean ice cover. The intrusion of warm Atlantic water combined with the on-going reduction of the sea-ice cover, will have major impacts on the unique Arctic fauna and ecosystems and human inhabitants.

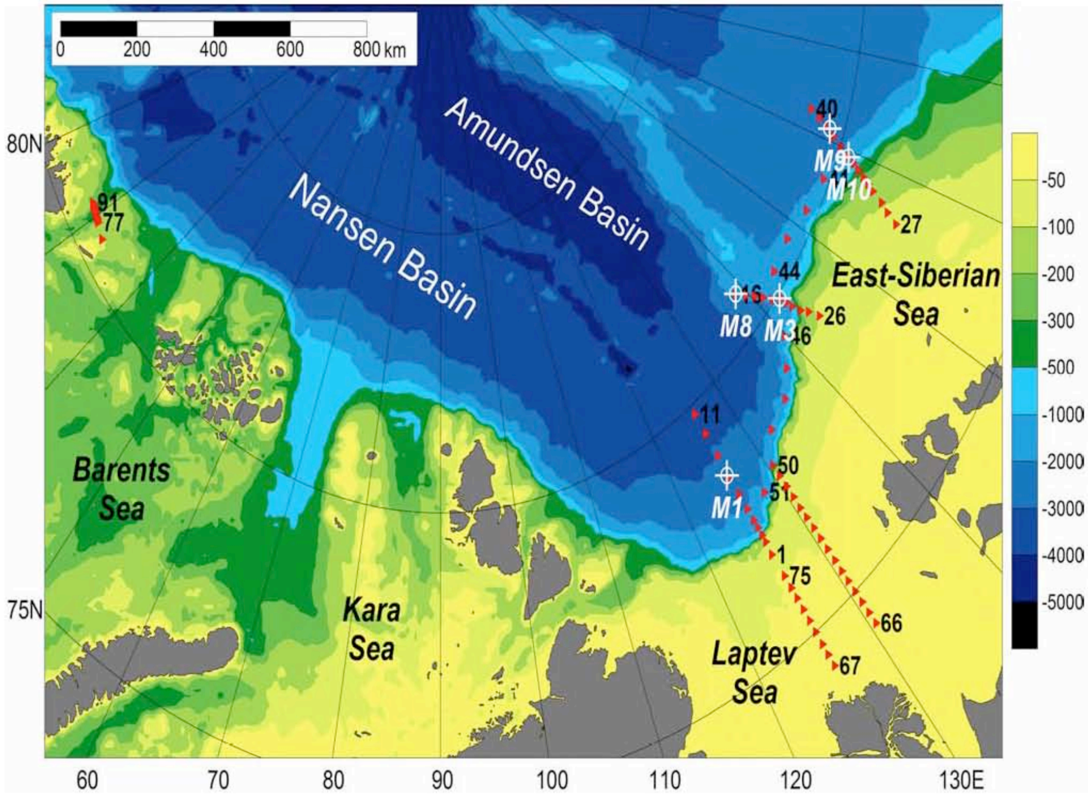


Figure I.6.1: Map of NABOS-07 operations: red triangles show CTD and XCTD stations, black numbers show station numbers, white crosses show NABOS moorings

c. Siberian Shelf Study
Contact Person: Igor Semilitov, IARC

The Siberian Shelf Study project is funded by the Arctic Research Program via an Earmark to IARC. In the summer of 2007 the US-Russian biogeochemical group joined the NABOS cruise, extending the study area to the outer shelf. The main objectives were:

1) Estimate the geographic variability of the main carbon cycle components, including partial pressure of CO_2 (pCO_2) colored dissolved organic matter (CDOM), and dissolved organic carbon/particulate organic carbon (DOC/POC), and water mass parameters including currents, water temperature and salinity, pH, total alkalinity, oxygen, turbidity, and stable oxygen isotopes.

2) Investigate the connection between seasonal anomalies of CO_2 and CH_4 in shelf water and dynamics of the water mass in connection with Lena River runoff (lateral fluxes).

3) Identify the particular sources of CH_4 and CO_2 within the shelf area, and the factors that affect sea surface-atmosphere CH_4 and CO_2 exchange (vertical fluxes).

4) Provide a benchmark of the composition and provenance and elucidate the extent of degradation of the terrOC currently being exported by coastal erosion and river runoff onto the extensive Siberian Arctic shelf.

5) Examine the transport and fate of terrestrial POC vs. marine OC.

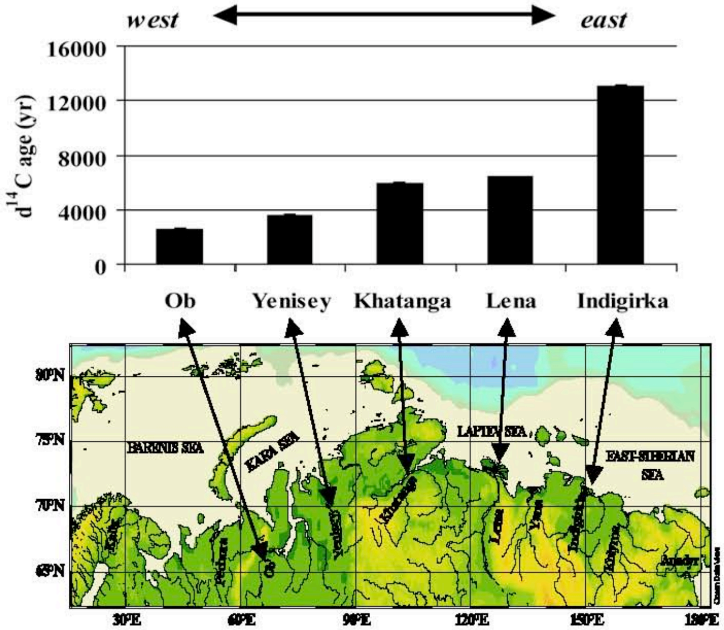


Figure I.6.7.3 The average age of bulk organic carbon in surface sediments collected from the mouths of Russian Arctic rivers along the entire continental margin [after Guo et al., 2004]

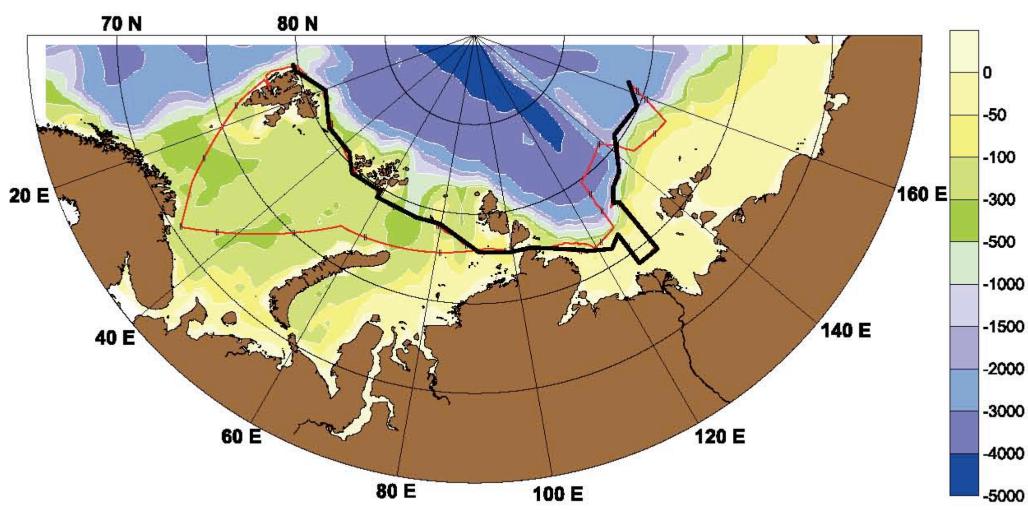


Figure I.6.7.4.6. Ship's tracks accompanied by pCO_2 measurements in the surface water.

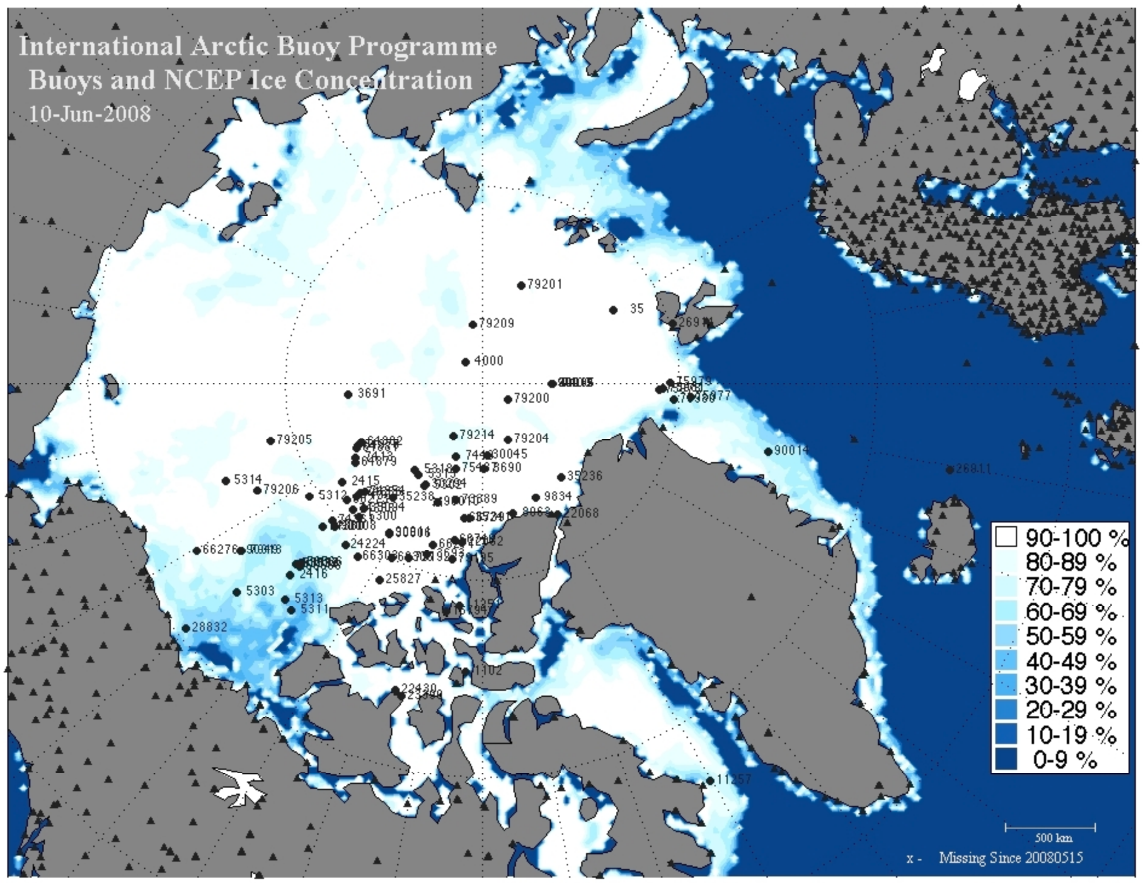
3) Ice Buoys
Contact Persons: Ignatius Rigor and Jackie Richter-Menge

The Arctic Research Program funds efforts to expand the International Arctic Buoy program and to carry out ice mass balance measurements of the perennial Arctic sea ice to measure sea ice drift, thickness and melt processes and basic meteorology; Monitoring changes in the volume or mass of the Arctic sea ice cover is crucial for developing our understanding of climate change processes and their impacts. Changes in the volume of the ice cover can result from changes in the ice extent (area) or ice thickness. The extent of the Arctic sea ice is effectively monitored by aircraft and from satellites. Monitoring the ice thickness is more challenging. Current satellites cannot measure ice thickness, therefore data sources are limited to on-ice mass balance measurements and submarine or seafloor-mounted upward looking sonars. Developing a coordinated network to monitor changes in the ice thickness of the ice cover is the focus of one aspect of the NOAA SEARCH initiative. A key objective of this study will be to establish international partnerships and to build upon existing programs such at the North Pole Environmental Observatory (NPEO) and the International Arctic Buoy Program (IAPB).

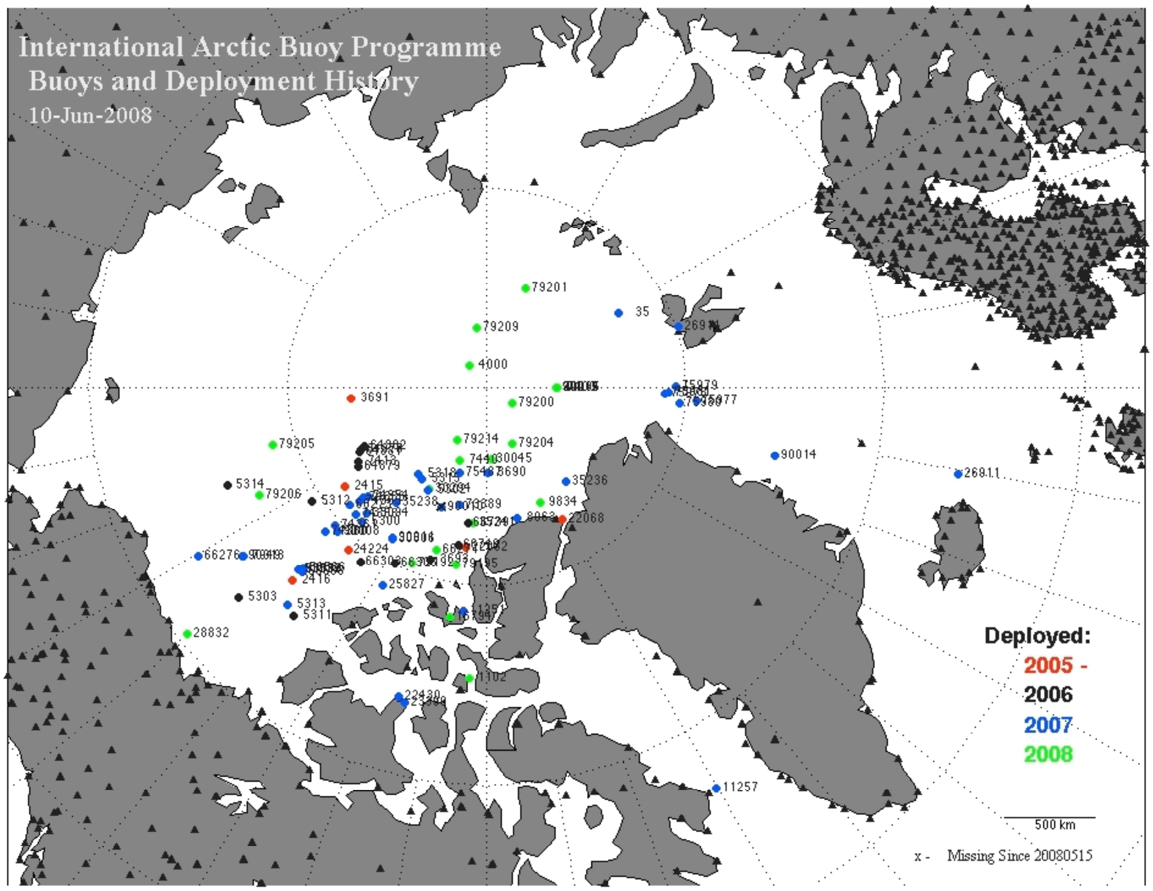
The participants of the IABP work together to maintain a network of drifting buoys in the Arctic Ocean to provide meteorological and oceanographic data for real-time operational requirements and research purposes including support to the World Climate Research Programme (WCRP) and the World Weather Watch (WWW) Programme.

Data from the IABP have many uses. For example:
1. Research in Arctic climate and climate change,
2. Forecasting weather and ice conditions,
3. Validation of satellites,
4. Forcing, validation and assimilation into numerical climate models, and
5. Tracking the source and fate of samples taken from the ice.
Over 500 publications have benefited from observations from the IABP!

The U.S. contributions to the IABP are coordinated through the U.S. Interagency Buoy Program (USIABP), which is managed by the U.S. National/Naval Ice Center, and the Polar Science Center, and represent several U.S. agencies, including the International Arctic Research Center, the National Aeronautics and Space Administration, the National Oceanic and Atmospheric Administration, the National Science Foundation, the Naval Oceanographic Office, the Office of Naval Research, and the U.S. Coast Guard.



Location of the Arctic Ice buoys, June, 10, 2008.



Deployment Timeline of Arctic Sea Ice Buoys. Buoys deployed in 2007 are colored Blue.

Jackie Richter-Menge, ERDC-CRREL, funded by the Arctic Research Program, led an international team of research scientists as chief editor of the recently released 2007 Arctic Report Card. The peer-reviewed web site tracks multiple changes in the Arctic environment, providing a concise, scientifically credible, and accessible source of recent observations. The Report Card is organized by the National Oceanic and Atmospheric Administration (NOAA) and will be updated annually. Richter-Menge and Dr. Don Perovich (CRREL research geophysicist) also contributed to the following Sea Ice Cover section of the Report Card.

Sea Ice Cover

J. Richter-Menge[1], S. Nghiem[2], D. Perovich[1], I. Rigor[3]

1ERDC-Cold Regions Research and Engineering Laboratory, Hanover, NH
2Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA
3Polar Science Center, Applied Physics Laboratory, University of Washington, Seattle, WA

Extent and Thickness

Satellite-based passive microwave images of the sea ice cover have provided a reliable tool for monitoring changes in the extent of the ice cover since 1979. During 2006 the minimum ice extent, typically observed in September, reached 5.9 million km2 (Figure I1, bottom left panel). This marked a slight recovery from the record minimum of 5.6 million km2 for the period 1979-2006, observed in 2005. Consistent with the past several years, the summer retreat of the ice cover was particularly pronounced along the Eurasian coastline. A unique feature was the sizeable isolated region of open water apparent in the Beaufort Sea.

The 2007 summer sea ice extent marked a new record minimum, with a dramatic reduction in area of coverage (4.3 million km2) relative to the previous record set just 2 years ago in 2005 (Figure I1, bottom right panel). At the end of the 2007 melt season, the sea ice cover was 23 percent smaller than it was in 2005 and 39 percent below the long-term average from 1979 to 2000.

The maximum ice extent is typically observed in March. In 2006, the maximum extent was 14.4 million km2 and set a record minimum for the ice-extent maximum for the period 1979-2006 (Figure I1, top left panel). It is notable that in March 2006 the ice extent fell within the mean contour at almost every location. In March 2007, the maximum ice extent was 14.7 million km2 (Figure I1, top right panel).

For comparison, the mean ice extent for March and September, for the period 1979-2007, is 15.6 million km2 and 6.7 million km2, respectively.

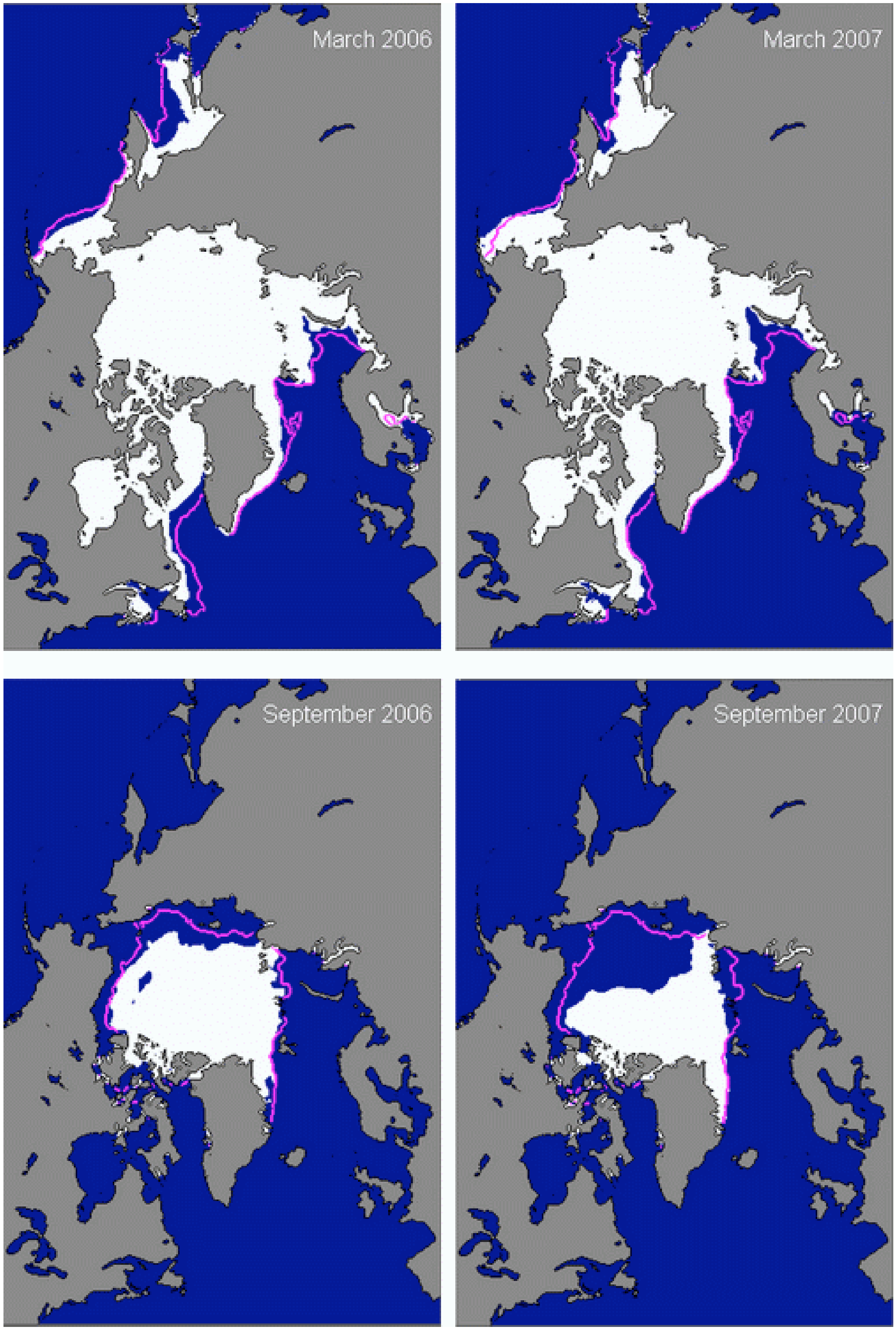

March 2006
March 2007
September 2006
September 2007

Figure I1. Sea ice extent in March and September 2006 and 2007, when the ice cover was at or near its maximum and minimum extent, respectively. The magenta line indicates the median maximum and minimum extent of the ice cover, for the period 1979-2000. The March 2006 maximum extent and the September 2007 minimum extent established new records as the lowest extents for the period 1979-2007. (Figures from the Sea Ice Index, nsidc.org/data/seaice_index)

To put the 2006 and 2007 minimum and maximum ice extent into context, the time series of the anomaly in ice extent in March and September for the period 1979-2007 is presented in Figure I2. In both cases, a negative trend is apparent with a rate of 2.8% per decade for March and 11.3% per decade for September relative to the 1979 values. The summers of 2002-2007 have marked an unprecedented series of extreme summer ice extent minima.

Ice thickness is intrinsically more difficult to monitor. With satellite-based techniques (Laxon et al., 2003; Kwok et al., 2004) only recently introduced, observations have been spatially and temporally limited. Data from submarine-based observations indicate that the ice cover at the end of the melt season thinned by an average of 1.3 m between the period 1956-1978 and the 1990s, from 3.1 m to 1.8 m (Rothrock et al., 1999). Measurements of the seasonal and coastal ice cover do not indicate any statistically significant change in thickness in recent decades (Melling et al., 2005; Haas, 2004; Polyakov et al., 2003).

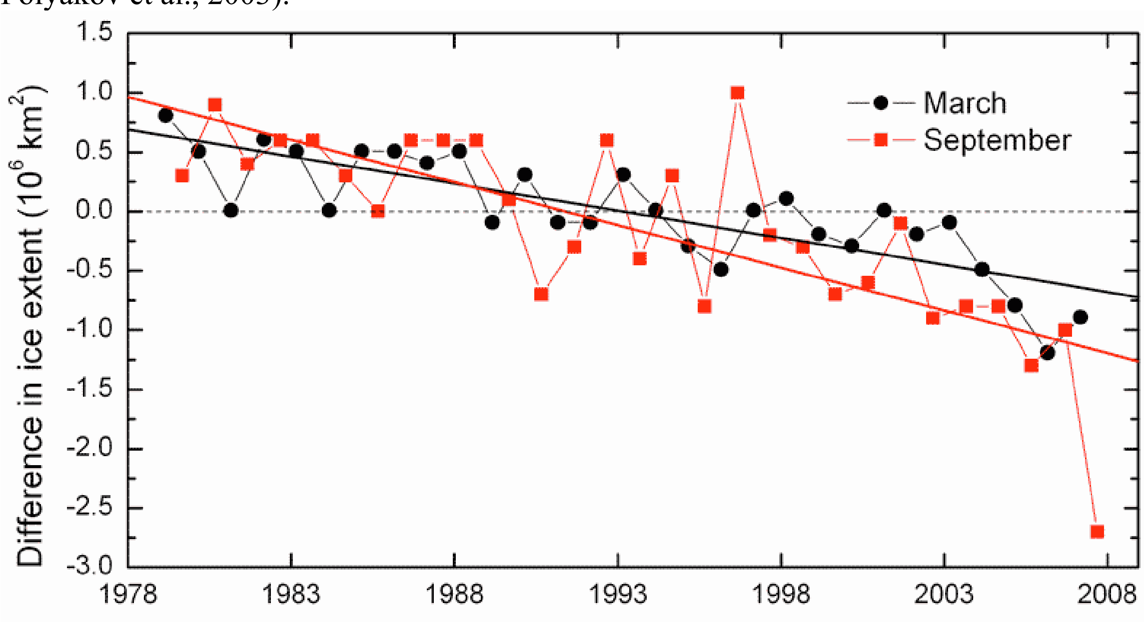


Figure I2. Time series of the difference in ice extent in March (the month of ice-extent maximum) and September (the month of ice-extent minimum) from the mean values for the time period 1979-2007. Based on a least squares linear regression, the rate of decrease for the March and September ice extents was 2.8% per decade and 11.3% per decade, respectively.

Perennial and Seasonal Ice

The Arctic sea ice cover is composed of perennial ice (the ice that survives year round, generally located towards the center of the Arctic basin) and seasonal ice (the ice around the periphery of the Arctic basin that melts during the summer). Consistent with the diminishing trends in the extent and thickness of the cover is the observation of a significant loss of the older, thicker perennial ice in the Arctic (Figure I3). Results from a simulation using drifting buoy data and satellite-derived ice concentration data to estimate the age distribution of ice in the Arctic Basin (Rigor and Wallace, 2004) indicate that the March ice cover has experienced a significant decline in the relative amount of perennial ice over the period 1958-2006, from approximately 5.5 million km2 to 3.0 million km2. While there is significant interannual variability, a generally downward trend in the amount of perennial ice begins in the early 1970s. This trend appears to coincide with a general increase in the Arctic-wide, annually averaged surface air temperature, which also begins around 1970 (Figure A2).

Results from a new technique employing data acquired by the U.S. National Aeronautics and Space Administration (NASA) SeaWinds scatterometer on board the QuikSCAT satellite (QSCAT) have recently become available (Nghiem et al. 2005; Nghiem et al.; 2006, Nghiem and Neumann, 2007). In the half decade of overlap with the buoy-derived results, which presently begins in 2002 and represents the period of data reprocessed to date by the QSCAT project, the two products provide consistent estimates of perennial ice in March and suggest a precipitous decrease in the perennial ice extent in the last few years.

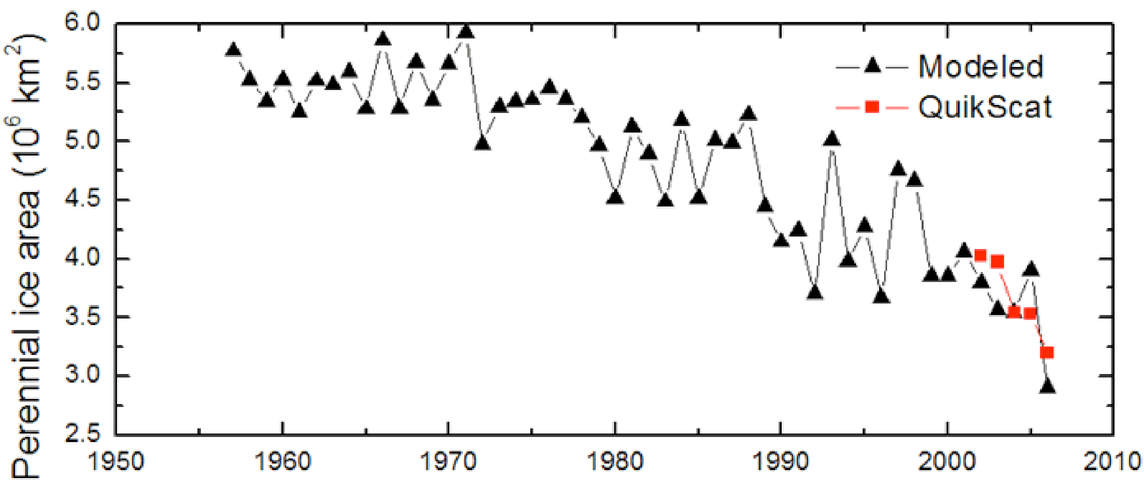


Figure I3. Time-series of the area of perennial sea ice extent in March estimated by a drift age model and satellite-derived ice concentration data and observed by the QuikSCAT scatterometer within the drift age model domain.

Figure I4 presents a comparison of the ice distribution derived from the drift age model and observed by QSCAT in March 2006. The two products provide similar results. Both indicate that the older, thicker ice is concentrated in the western Arctic basin. This result is consistent with the dominant ice circulation patterns in the Arctic (see Figure O1). Ice residence times are typically longer in the western Arctic in the region of the Beaufort Gyre. The eastern Arctic is dominated by the Trans Polar Drift, which carries sea ice out of the Arctic Basin via the Fram Strait.

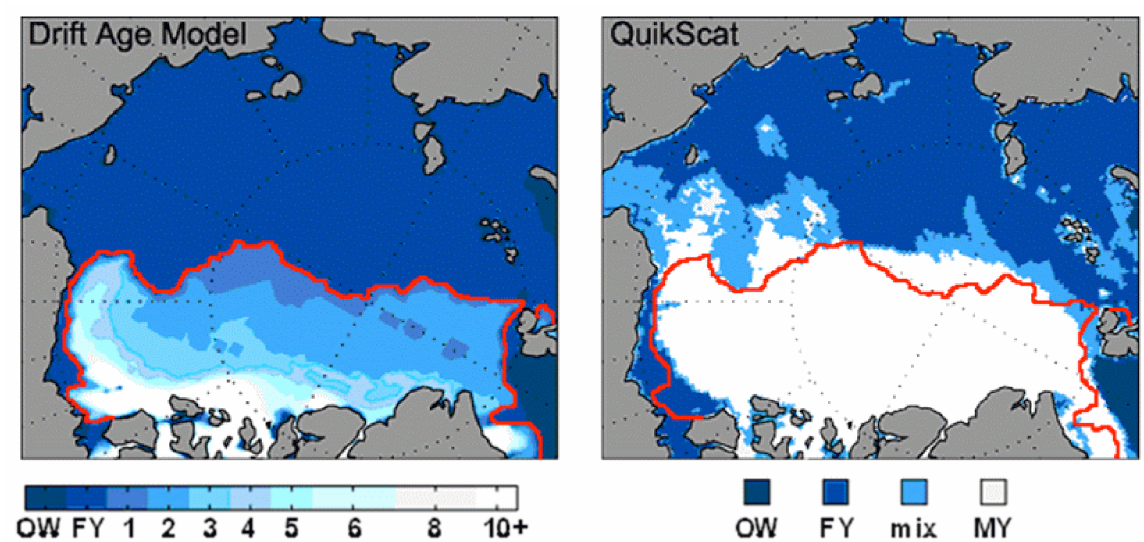


Figure I4. Comparison of sea ice distribution estimated using the drift-age model (March average, left panel) with QSCAT observations (21 March 2006, right panel). The red line in both panels indicates ice age older than 1 year (i.e. perennial ice) as estimated by the drift age model.

The development of a relatively younger, thinner ice cover coincided with a strong, persistent positive pattern in the AO from 1989 to 1995 (see Figure A1). These characteristics make the current ice cover intrinsically more susceptible to the effects of atmospheric and oceanic forcing. It is of crucial importance to observe whether the sea ice cover will continue its decline or recover under the recent more neutral AO conditions (Lindsay and Zhang, 2005).

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4. ***Arctic Change Detection***
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The NOAA Arctic Research Program supports the **Arctic Climate Change Detection Protocol**. Historical and current data from diverse sources is assembled to evaluate variability and change in Arctic climate.

The Arctic Change Detection Activity had the following goals in 2007:
1) Maintain an up-to-date Arctic climate change detection activity for NOAA that includes improved understanding of Arctic climate variability, communication of Arctic change to policy and scientific forums, chairing committees, the Arctic Report card/State of the Arctic Report, and research publications.
2) Support and enhance NOAA's mission in climate variability and impacts in the Pacific sector of the Arctic. Use the North Bering and Chukchi data base to develop a paper that puts RUSALCA data in a historical context back to 1880.

NOAA has an important role in providing a scientifically credible perspective on Arctic climate research and ecosystem impacts, in addition to contributing to international planning and scientific advancement. the Arctic Change Detection projects support four of the strategies outlined to meet NOAA's Strategic Goal in Climate:

- Develop and contribute to state-of-the-science assessments of the climate system for informed decision-making
- Support educational efforts to create a more climate-literate public
- Improve the quantification and understanding of the forces bringing about climate change
- Develop the ability to predict the consequences of climate change on ecosystems

Overview:
A primary goal in 2007 was to evaluate and communicate the results of the IPCC Fourth Assessment Report (IPCC AR4) model hindcasts and projections for Arctic and sub-Arctic climate and ecosystem impacts. In addition the Arctic Change Detection Activity was engaged at the center of evaluating the causes for the record minimum sea ice extent in September 2007.

1. The Arctic Change Detection Effort carried out the following activities in 2007 aiimed at communicating Arctic Change and Impacts

- For IPCC, Overland led the AMAP and ESSAS task teams and contributed to the USARC AMSA Bering Strait Regional Case Study.
- Overland served on the NOAA Biological Response Team (BRT) for Ribbon seals' EIS (now all ice seals) and the US Marine Mammal Commission.
- The Change Detection team has given four invited keynote presentations, attended three workshops, plus prepared major AGU and Alaska Marine Science Symposium talks. These included the DAMOCLES meeting in Oslo, the Synthesis of Arctic System Science (SASS) Group at IBM, NY, and the NATO Arctic workshop in Belgium in May.
- Overland hosted the SCAR - CliC – IASC – ICPM Second Workshop on Recent High Latitude Climate Change on October 2007. An EOS article will be published in May 2008.
- Five journal papers have been written during this period.

2. Continued the *Arctic Reportcard*

The Reportcard is adopted as a product of the AMAP Climate Expert Group.

3. Research Areas

A. *IPCC model projection results for Arctic and subarctic seas*
The Arctic Change Detection Team has published a GRL paper on regional sea ice projections from IPCC models.

The team is currently working with Vladimir Kattsov and John Walsh on a grand synthesis for the Arctic to be completed during the summer of 2008.

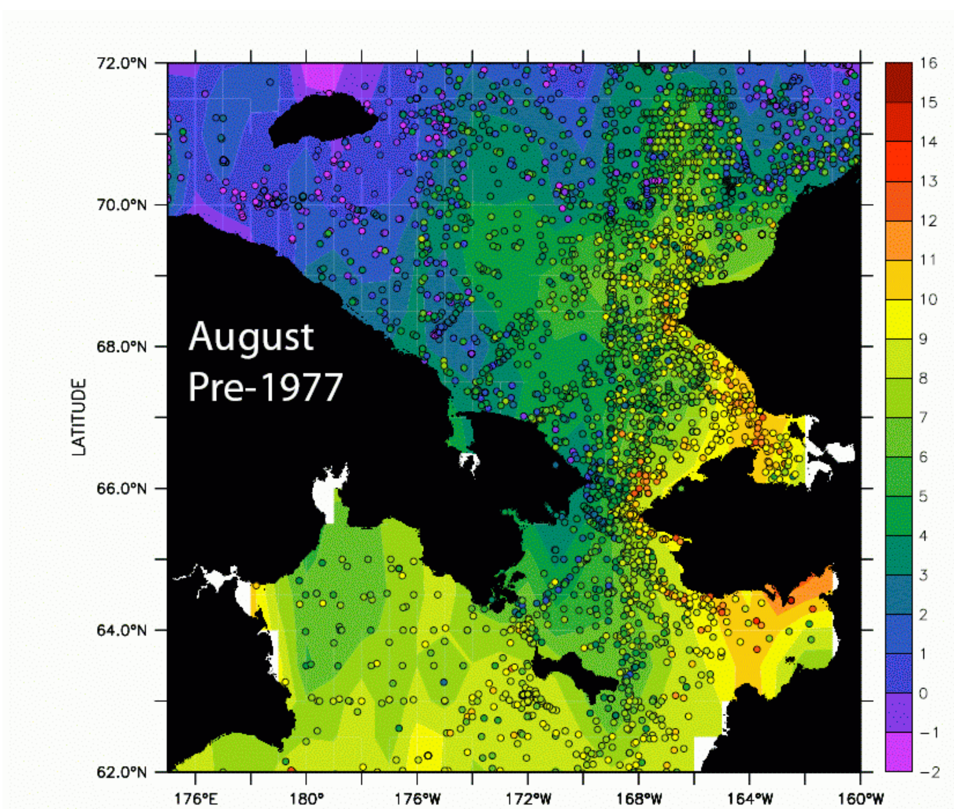
B. *Historical Arctic climate*
The Arctic Change Detection Team has a comprehensive *Journal of Climate* paper on the early 20th century warming in review, including a literature survey of what climate scientists thought about the changes that were occurring at the time and a new data synthesis. Work will continue with data from the 19th century. Overland contributed to a paper in press in *Journal of Climate* that evaluates Baltic Sea ice conditions back to 1500.

Northern Bering Sea

Overview:
The Arctic Change Detection Team has a goal is to bring together all oceanographic physical data for the northern Bering/southern Chukchi Seas and to make this data available and accessible through search software.

Historical Analysis of Bering Strait Oceanography. The team is completing a draft of a paper, which exercises the Northern Bering/Chukchi data base. It first looked at changes for all months at Nome for 1907-2006. No major shifts or decadal variability are seen before 1977. This fact was used to bin oceanographic data for two periods, before and after 1977 for three months, July, August and September. These composites provide a baseline for comparison to new RUSALCA data.

Ocean temperature data from the World Ocean Database (WOD05) were downloaded from the Ocean and Weather Data Navigator (http://dapper.pmel.noaa.gov/dchart/) for the region 175°E – 160°W, 62° – 72°N and compared with other sources. After editing the dataset consists of 18,698 oceanographic profiles. While the earliest profiles in the dataset were collected in 1855, the dataset includes only 32 profiles prior to 1925. The scattered profile data were transferred to a regular grid using objective mapping. Coherent spatial patterns lend confidence to our results. Below is the near surface ocean temperature field before 1977 for August and its spatial data distribution:



Website Development

Nancy Soreide and her web group will continue to provide updates, new material, and web support for the NOAA Arctic Theme Page and Arctic Research Program. Timely updates are the key to information transfer, especially with recent fast moving Arctic change. The NOAA Arctic Theme Page is consistently one of the top Google results for keyword "arctic", and was visited by 91,053 unique hosts from 144 countries in March 2008. Support includes search engine optimization, website promotion, maintaining the Website in the PMEL Web Farm environment, adding and updating information and links, assuring that webmaster email is answered promptly, participating in IPY website planning activities, and posting or updating information as requested by the Arctic Research Program. We contact authors of Expert Essays (http://www.arctic.noaa.gov/essay.html) to ask for updates, install the updates that are provided, and seek new Expert Essays. In addition to these standard activities, a priority in 2008 is to update information on NOAA Arctic research activities.

Arctic Monitoring and Assessment Program and the Pacific Arctic Group

The Arctic Research Program is an active participant in several International organizations including Chairing the Arctic Monitoring and Assessment Program and the Pacific Arctic Group. AMAP is an international organization established in 1991 to implement components of the Arctic Environmental Protection Strategy (AEPS).

Now a programme group of the Arctic Council, AMAP's current objective is "providing reliable and sufficient information on the status of, and threats to, the Arctic environment, and providing scientific advice on actions to be taken in order to support Arctic governments in their efforts to take remedial and preventive actions relating to contaminants".

In 2007 AMAP released its Oil and Gas Assessment. This assessment of oil and gas activities in the Arctic was prepared in response to a request from the Ministers of the Arctic council. The Ministers called for engagement of all Arctic Council Working Groups in this process and requested that the arctic Monitoring and Assessment Programme take responsibility for coordinating the work. The objective of the 2007 "Assessment of Oil and Gas Activities in the Arctic' is to present an holistic assessment of the environmental, social and economic, and human health impacts of current oil and gas activities in the Arctic, and to evaluate the likely course of development of Arctic oil and gas activites and their potential impacts in the near future. The assessment updates information contained in the AMAP 1997/98 assessment reports, including several aspects not covered in the earlier assessments.

NOAA's contributions to the Pacific Arctic Group are also significant. Organized under the International Arctic Science Committee (IASC), the PAG has as its mission to serve as a Pacific Arctic regional partnership to plan, coordinate, and collaborate on science activities of mutual interest. PAG has ten principle science themes:

* Theme 1:Undertake seasonal and interannual ocean observations in the Pacific Arctic Sector where recent maximum sea ice retreat is occurring.
* Theme 2: Understanding oceanic and atmospheric processes in the Pacific Arctic, including the feedback loops, are critical to mid-latitude climate variability.

* Theme 3: Monitoring fresh water input via precipitation, riverine input, oceanic input, glacial and sea ice melt in the Pacific Arctic sector will improve our understanding of mid-latitude climate variability and provide additional information to support theme 1.
* Theme 4: Identify and monitor ecosystem and biological indicators (ice, water column, benthic, higher trophic organisms) of climate change in the Pacific Arctic.
* Theme 5: Investigate sea ice thermodynamics including sea ice thickness, extent, and its interactions with ocean and atmospheric forcing in the Pacific Arctic region. Investigate sea ice dynamics such as sea ice drift, interactions between different ice packs.
* Theme 6: Understanding the connectivity of warm Atlantic inflow to the Pacific sector, heat flux throughout Arctic, and associated biodiversity/invasion of Atlantic-species into the region. Physical gateways should be mapped and monitored, including outflow through the Canadian Arctic Archipelago.
* Theme 7: The Arctic Ocean is very poorly mapped from the seafloor to the ice above. Significant information gaps include the bathymetry, biodiversity, and knowledge of ocean currents and their variability over space and time. Exploration of the unknown Pacific Arctic region is essential for the construction of base maps necessary for the planning of future monitoring efforts.
* Theme 8: The Pacific water inflow through the Bering Strait region is a key conduit for heat, salt, nutrients, and biological material (including genetic material) to the Arctic basin that influences sea ice cover, halocline formation, and the carbon cycle.
* Theme 9: Nearshore coastal processes and subsea permafrost dynamics are important processes in the shallow Pacific shelf areas are subject to climate change impacts.
* Theme 10: The open and closing of the Pacific gateway has occurred over geological time periods with dramatic impact on the Arctic system. The paleorecord provides a long-term record for comparative evaluation of climatic processes relative to contemporary studies in prior themes. In 2007 PAG has initiated an effort to carry out a Pacific Arctic Group Regional Synthesis of Ocean Data and Information --A Contribution to the International Polar Year (IPY) Global Synthesis.

Partnerships

The Arctic Research Program is highly leveraged. All of the AON activities described above and the IASOA site at Tiksi involve collaboration with the Russian Federation. NOAA Arctic Research has played a critical leadership role in developing and formalizing functional scientific linkages with Russian agencies and scientists. A Memorandum of Understanding between NOAA and the Russian Academy of Sciences on World Oceans and Polar Region studies was signed in December 2003, and this has proved to be a critical document for obtaining Russian support of our activities. This MOU under the U.S. – Russian Federation Science Technology Agreement is also an umbrella for NSF funded collaboration with Russia. Over the past few years, many meetings, teleconferences and e:mail exchanges were conducted with Russian officials and scientists to plan the joint activities, obtain the necessary formal “permissions” from involved Russian agencies and to arrange for visits by US scientists to Moscow, St. Petersburg, Tiksi, Petropavlosk and Vladivostok. The maintenance of good working relationships with Russia requires constant attention.

In addition to Russia, many other countries will be involved in establishment of Arctic Observing systems and the Arctic Research Program tries to collaborate with these countries. In particular, collaborative efforts with Canada, Finland and Norway are underdevelopment. China, Korea and Japan also have expressed interest in working with NOAA during the International Polar Year.

The Arctic Research Program has purposely designed observation programs to be interdisciplinary in scope to identify interactions between physical, chemical and biological processes that affect climate variability. The Arctic Research Program helps to facilitate interactions between modelers and observationalists to improve the ability to forecast weather and climate in the Arctic and the global environment.

To carry out its goals, the NOAA Arctic Research Program, COD, works with other NOAA groups, (NMFS, PMEL, ESRL), other U.S. agencies, such as NSF, and DOI, cooperative institutes at Woods Hole, University of Washington, University of Colorado, and the University of Alaska, Fairbanks. Numerous investigators have been funded to carry out the climate objectives of the Arctic Research Program (from the University of Alaska, the University of Washington, the University of Tennessee, the Smithsonian Institution, Woods Hole Oceanographic Institution and Pt. Stephens Research). Both the Bering Strait mooring nettwork an d the Tiksi Observatory are co-funded by the National Science Foundation

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